AGARDograph

WIND TUNNEL
DATA PROCESSING

by

Robert E. Covey

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NORTH ATLANTIC TREATY ORGANIZATION
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This is one of a series of Wind Tunnel AGARDographs concerned with wind tunnel design, operation, and test techniques. Professor Wilbur C. Nelson of the University of Michigan is the editor.

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This report serves as an introduction to the problem of defining and selecting an automated data processing system for a wind tunnel facility. The restraints imposed by speed and accuracy requirements, and the characteristics of various facilities and types of testing are discussed. Typical systems and system elements are described. A tabulation listing the present data processing systems for many wind tunnel installations and a sample specification for a modern system are included. AUTHOR

I. INTRODUCTION

A. Introductory Remarks

Wind tunnels are used for the testing of scale models of air frames, missiles, and aerodynamic entry configurations of space vehicles, or for the full-scale testing of ramjet and gas turbine engines or components. From the early days of aircraft development, wind tunnel experiments have involved a considerable amount of instrumentation and processing of the acquired data by manual means. In the past decade, the rapid development of high-speed automatic computers has permitted more extensive calculations, and the automatic instrumentation to feed data into a computer has followed as a logical consequence.

This report is written by a test facility engineer, not a data handling specialist, computer programmer, or electronics engineer. It is basically addressed to other facility operational or test engineers, or those who wish to view the problems of wind tunnel data processing from that vantage point. It is an attempt to pass on some of the Jet Propulsion Laboratory (JPL) experiences concerning the definition and selection of an integrated data processing system. It is hoped that the things we have learned would be of interest and use to another facility operator embarking on a system analysis and design project. The near optimum solutions in terms of specific hardware are rather transient due to constant advances in the state-of-the-art resulting in both improvements in present equipment, and completely new equipment. Recognizing this, and realizing that each facility's requirements are somewhat unique, the discussion is kept as general as possible.

B. JPL Experience

The data handling experience in the JPL wind tunnels is a composite of many of the experiences of other facilities. The JPL facilities (Reference 1) have been in operation long enough (15 years) to have witnessed and participated in the technical revolutions which carried from hand operation to fully automated systems. The operation has been diverse enough (from the extremes of high priority military development testing to basic research work) to raise the gamut of operational problems. During this period JPL has also experienced the management variations inherent in growth from a 1000- to a 4000-man laboratory, addition of new facilities, and a change of direction (in the wind tunnels) from military ownership, through a brief fling at quasi-private enterprise, to the present operation by a university under contract to NASA. In each area: operation of the facilities, acquisition of the data, reduction or computation of the data, and presentation of the results, JPL has passed through several phases. Some new systems affected all phases, while other changes or modifications only improved one area at a time.

To a limited extent, a brief description of the history of wind tunnel data processing at JPL can thus double as a brief history of the field in general. It is not all-inclusive, but is probably more representative than the experience of many others who arrived on the scene more recently, or who perhaps skipped some of the intermediate steps in their quest for better methods. This history is summarized in Table I-1. Reference to this table shows that during this 15 year period the system has progressed from a completely manual research-type test operation to the present integrated system which will be described in greater detail in this report. The operation of the tunnels has been automated little by little through the years. Not shown on the Table I-1 listing of major milestones are thousands of operational improvements such as the modification to central-control operation of over 100 valves in the compressor plant, improvements in the air drying system, and improvements in the test setup and installation techniques, and compressor plant and tunnel maintenance. These features have certainly contributed their share to the large amount of rapidly-available test results by increasing the tunnel efficiency and run-rate and reducing the facility down time.

C. System Justification

Whenever a test facility is expanded, modified, or improved, the engineer must justify the costs involved on economic and technical grounds. The detailed justifications required to cover a large integrated data processing system represent a significant proportion of the overall problem. The system usually cannot be explained on either straight technical or purely economic grounds. The arguments advanced represent a combination of these reasons. Basically, vehicle testing can no longer be accomplished by rule-of-thumb procedures. The research test program is exposed to too many unknown factors. The testing must seek knowledge on a cumulative basis with succeeding steps based on immediately preceeding tests combined with the required design or test objectives. To be able to synthesize this knowledge, the aerodynamicist should be presented with data in an easily digestible form whose validity and reliability are keyed to a satisfactory confidence level. Thus timeliness is a primary reason for resorting to automation where large quantities of data must be processed but the economic factors in large manpower saving is equally important.

In the selection of wind tunnel test equipment, heavy emphasis must be placed on system and component reliability. Equipment reliability is a key factor in obtaining high production. Unscheduled maintenance should be avoided if possible, and scheduled maintenance should be organized to minimize the reduction of time available for facility operation. Since the operating costs of wind tunnel facilities are generally very high, high production must be achieved in order to obtain data at a relatively low unit cost.

Another major argument advanced for the advantages of automation has to do with accuracy, both indirect and direct (Reference 2, pg. 291).

"Inaccuracies in manual data handling processes cause excessive time delays as well as erroneous test results (indirect accuracy). If a study is made of virtually any manual data process from acquisition to final results, each and every number that is used must be read, transcribed, calibrated, or operated on in some manner between five and ten times. When final answers have been arrived at, even though a computer has been used to do all the computational operations on the data, extensive time is required to evaluate suspicious results and isolate erroneous data. If engineers or high quality technicians are utilized for the manual data processing, fewer errors are apparent. This is not usually the case, however, where the menial tasks are concerned, such as film reading, calibrations or transcriptions. Errors invariably occur in misreadings, inverting numbers, transcribing data, poor handwriting, etc. These errors are inherent in data when handled manually and are extremely time consuming for the engineer or analysis staff to isolate since many times a single number must be traced not only back to the recording medium such as film or oscillograph, but also to the transducer itself before the source of an error may be determined. If manual computational operations are made, as compared to computer computations, a proportionally larger number of induced errors will be inherent in the final results. Through the medium of automatic data handling systems the data are 'uncontaminated' by human interference and as a result very little time is expended on isolating random errors. It should not be construed that automatic systems are infallible--they definitely are not--however, when an error is made it is usually very obvious and can be isolated rather rapidly. If an equipment failure is the cause of erroneous results considerable time may be required to remedy a given situation. However this is not time lost and effort spent by the engineering or analysis organizations who can profitably expedite other portions of a given program during the same period."

"The direct aspect of accuracy that is a definite factor in favor of automatic systems is the much more sophisticated manner in which data can be handled. The basic accuracy of any one given data point that has been processed through an automatic system is usually no better, and in some cases slightly worse than that which may be obtained on a conventional photo-panel or oscillograph system. Because of the relatively high frequency of parameter sampling obtainable on tape systems as compared to the data frequency required for performance tests, it is possible to make use of computer programs encompassing statistical data handling methods in smoothing routines. Since the normal scatter of any given parameter is random in nature these methods present a means of obtaining more accurate test results than can normally be achieved by conventional methods. Depending on the number of points and the rate at which the parameters are sampled, the average random error can be decreased by a factor of 3 to 5. Though the same procedures are technically feasible with data reduction on a photo-recorder or oscillograph, the excessive number of points which must be processed manually makes it impractical."

D. System Selection Philosophy

The philosophy which we have found to be a valid approach to the problem of obtaining a satisfactory integrated wind tunnel data processing system consists of three major parts. First, we define the overall problem as precisely as possible, then we specify a general system which should handle this design problem, and finally we evaluate the systems and equipment offered by the bidders to meet this specification. To carry out this philosophy, a special organization was formed. The team approach was emphasized. A senior project engineer with the title of Data System Coordinator was put in charge. Supporting him were engineers from the Facilities Operation Section, Instrumentation Section, and from the Computing and Data Handling Section, as well as special support from Procurement and other Laboratory elements. A definite time schedule was set up to complete the phases of problem definition, system specification, and bid and evaluation. Based on funding considerations, a target cost for the system was derived. Management was then sold on our ability to obtain a satisfactory system within this target cost and in a reasonable time.

This approach of problem definition, system specification, and proposal evaluation will be discussed in greater detail in the succeeding sections.

II. Problem Definition

A. Ideal System

A good way to begin a system definition is by describing an ideal (but unattainable) system. Then perhaps we can degrade this paragon into a practical system and yet retain a sufficient proportion of its ideal characteristics. Briefly, the ideal system should be able to record all data instantaneously with absolute accuracy, and to instantly present it in such a lucid fashion that error-free decisions can be made. This ideal system, providing "instant knowledge for infallible decisions" will be kept in mind as we ask and answer the general and detailed questions which describe the system.

The most general questions are as follows: 1) What kinds of problems will we be trying to solve, and what will be the significant data that we will generate? 2) In what quantities and at what speeds shall these data be recorded? 3) What is to be done with the recorded data; what shall be the nature of the computations required? 4) What shall be the form of presentation of the resultant computations? 5) What shall be the significant limit of error in the results? The answers to these questions tell us 1) the required mode of operation; steady state, dynamic, or both, 2) the nature of the input data; pressure, temperature, strain, etc., 3) the required scanning and logging rates, 4) the necessary data channel capacity, 5) the size and speed of the computer and its memory capacity, 6) the presentation equipment, 7) the system accuracy. Regarding the last item, firm statements of system accuracy and reliability are a matter of operational experience, although the versatility and cost of a data processing system can be established at the design stage.

B. System Elements

Before attempting to delve any deeper into the definition of the system it will prove useful and instructive to review the elements of a typical system. In general terms, a physical quantity is measured by some sort of transducer which provides an electrical output proportional to the measured quantity. This electrical output or signal is usually conditioned in many ways. It may be switched, amplified, filtered, smoothed, converted to a digital form, recorded on punched cards, paper tape or magnetic tape, or sent directly into an analog computer or assimilated in digital form by a digital computer.

1. Transducers and Signals

Let us begin with the sending element and follow through a typical system. The need to measure with minimum effect on the measured parameter on the small models encountered in wind tunnel testing dictates the use of strain gages and thermocouples as transducers. (References 3 and 4.) They may appear in configurations of pressure gages, heat meters, etc., but are still fundamentally strain gages and thermocouples. In fact, if some other transducer with the required resolution and predictible behavior were to be developed or used to measure model conditions (such as variable reluctance or capacitance gages, etc.) it would still have the same basic handicap of low-power signal levels. The fact that our system begins with a low-level signal is the cause of many problems, as will be noted in the discussion of other system elements.

2. Cabling and Shielding

A key element of any system is the cable and wiring which connects the other system elements. This wiring is a source of many spurious signals and a variety of noise. Where the signals are low level, the noise level can represent a significant portion of the signal, and reduction of such noise becomes a primary consideration in the system design. The noise cannot be completely eliminated, but can be greatly attenuated through careful attention to design details. One error source is the grounded circuit loop or common mode current which is caused by a voltage difference between different grounds, or by pickup between a pair of conductors. These ground currents or pickup can be controlled by careful attention to isolation or impedence balancing in the design. Signal grounds and power supply grounds must be isolated from each other to prevent ground loops. Another source of error is the thermo-electric junctions of dissimilar metals. Materials must be selected to avoid unwanted thermocouples. Large blocks of material may be utilized to provide temperature stability and a good design may include an actual isothermal box. Finally, a major source of signal noise arises from the fact that a conducting circuit element in a varying electro-magnetic field will have a current induced. The usual method of isolation consists of coaxial or triaxial cables, twisted pairs, etc., but even the shielding itself can have a large capacity to ground and provide an AC ground loop. Even mechanical vibrations can induce a current if the conductor is moving in an electro-magnetic or electro-static field. The reduction of the system signal-to-noise ratio through appropriate shielding and wiring design is of major importance, but requires a sound technical understanding of the problem. An excellent article on noise control in low-level data systems may be found in Reference 5.

3. Amplifiers

The low-level signals will contain two or more of the following components: A static or DC level, and a dynamic or flutter signal, and extraneous electrical noise. The instrument measuring these signals must be capable of: 1) amplifying the signal to usable levels without degradation; 2) distinguishing between the signal components; and, 3) presenting the measured value in a convenient form. There are many schemes for transforming the low level transducer signal into usable levels or forms. Two methods with proven reliability and accuracy will be considered.

a. Servo Instrument Amplifier (potentiometric)

The first is the null balance instrument utilizing a servomotor, such as a Fairchild or Brown Recorder. It continually seeks to null the signal voltage against the voltage developed by an output potentiometer positioned by a servo. Its ultimate resolution is determined by the servo "dead zone", internal noise generation, and potentiometer resolution. Its accuracy is determined, aside from resolution, by potentiometer linearity and attenuator stability.

In order to properly measure static conditions, the time varying signals of flutter and noise must be rejected. This implies low-pass filtering which is a fundamental property of the servo system, due to its mechanical inertia. However, this inertia coupled to its amplifier gain gives rise to a natural frequency of oscillation which must be avoided in the input signal.

The high-level output of this instrument is essentially the angular position of its servo shaft. This position can be easily detected visually by coupling to a mechanical counter or indicator dial. A digital output is normally obtained by a shaft-position encoding disk. A special requirement of this technique is that ambiguities in the encoded valve be prevented. Thus, the Gray or reflected binary code is used and this is converted by relay matrices into binary-coded-decimal.

b. Electronic Instrument Amplifier

This instrument differs little in principle from the servo system, but it employs no mechanical components. The high-level output voltage is attenuated by precision resistors and subtracted from the input voltage. The amplifier section, which has an open loop gain of several million, amplifies the error signal only. Gain accuracy and linearity, then, are essentially dependent only on resistor accuracy and stability, and resolution is limited by internal noise levels. DC drifts are effectively eliminated by modulating the input signal and utilizing an AC carrier amplifier. The output is a high-level, low-impedance analog voltage related to the input voltage by the gain setting. A tutorial description of the design and use of DC amplifiers may be found in Reference 6.

Fundamentally, this amplifier is a wide band instrument, but it's bandwidth is usually restricted in order to limit noise signals. A typical DC differential amplifier has a bandpass of 100 cycles. Therefore, static conditions are usually obtained by filtering the input. Differential, floating inputs effectively eliminate common mode signals.

The output cannot be visually displayed directly but must be displayed by an auxiliary instrument such as an X-Y recorder. An analog-to-digital converter is normally used to digitize the value.

c. Amplifier Comparison

Basic properties of these instruments are generally comparable; e.g., drifts and resolutions are on the order of three microvolts and linearities are better than 0.1%. Other features are less important to their primary function, but affect the characteristics of the system into which they are integrated. The following comparison is made on the basis of signal conditioning functions:

	Potentiometric	Electronic
Reference Supply Voltage	The same reference can be used for strain gages and the instrument so that a highly regulated reference is not needed for thermocouples. A separate reference is needed for thermocouples.	A separate reference is needed for gages and the A-D encoder so that a stable, regulated supply is needed.

	Potentiometric (Con'd)	Electronic (Con'd)
Component Reliability	Mechanical components experience wear which indicates periodic overhaul.	All solid state components with long life expectancy.
Visual Indication	Visual indication of output is readily obtained with counters or dials.	Visual indication must be provided by auxiliary instrument.
Response	Response speed has a low upper limit. Has a natural frequency to be avoided.	Speed is electronic and can be controlled by plug-in filters. Will not oscillate.
Size	Comparatively bulky.	Compact.
Digitizing	Code wheel output must be converted to computer code. Conversion circuits can be shared, but code wheels cannot.	Low impedance output can be sampled directly by a single A-D converter with a direct BCD output.

4. Commutators

a. High-Level Commutation

In a multichannel system, the various signals are recorded on a single medium. The method of commutation is determined by many factors such as recording medium, signal levels, signal frequency, recording time available, etc. Many different physical processes are utilized (such as mercury-wetted switches, etc.) by various manufacturers to supply a wide range of requirements. (cf Reference 7.)

When the signals are switched at the amplified or conditioned level, it is known as high-level commutation. It has the advantage that signals are not distorted at the low level by contact potentials. It has the disadvantage that an amplifier or servo instrument is required for each channel.

Cost comparisons of the two types of amplifiers for a high-level system show that for a very few channels, the servo balance system is less expensive but with any usual number of channels the DC amplifier system is cheaper. The reason is that an electronic A-D converter is more expensive than a shaft digitizer, but only one is needed. For example, if the A-D converter costs $5000 and the amplifiers $1000 apiece as compared to $2500 per channel for servo amplifier including individual digitizers, it will be seen that the DC amplifier system is more expensive for 1 to 3 channels but less expensive for 4 or more channels.

b. Low-Level Commutation

When signals are switched at the transducer output level, the signal conditioning instruments can be time-shared but switching noise is introduced into the low-level signal. However, at medium scanning speeds, gold contact stepping switches can be used to commutate. By switching three lines--two signal and a guard--contact potentials can be kept below 5 microvolts.

Before comparing the two amplifying instruments in a low-level commutation system, consideration must be given to settling times and channel rates.

In order to obtain optimum performance from a DC amplifier, its bandwidth should be limited. To be conservative, a low pass filter is employed at its input. When a signal is switched to its input, eight time constant periods of the filter must be allowed for the voltage to settle within 0.03% of its final value. For example, eight time constants for a 4 cps filter amount to 0.32 second which is more than the usual channel commutation time. Therefore, systems employ several amplifiers; one to be sampled while the others are settling.

A servo balance instrument has about 4 second full scale excursion time for the signal levels in question. Using the same technique of "leap frogging" channels, 36 instruments would be required to assure accuracy with only an eight per second channel rate.

This illustrates why servo balances are seldom commutated at low levels. DC amplifiers with their adjustable band width are ideally suited for low-level commutation.

5. Calibration and Monitoring

Before continuing on through the system let us compare the amplifier and servo systems with regard to system calibration and data monitoring.

Servo instruments have the capability of being scaled and offset by auxiliary attenuator circuits. Thus they can be calibrated directly in engineering units. Amplifiers cannot be offset, but they can be scaled by variable gain settings and by some control over gage exciter voltages. However, if low-level commutation is used, scaling of individual channels would be impractical. This is true of either instrument with low-level commutation.

An amplifier system of any size would certainly employ low-level commutation and suffer the disadvantage of non-engineering units in the raw data. This would shift the burden of conversion to the computer, but would also reduce set-up and calibration time. Set up would consist of connecting transducer leads to a terminal block and wiring a plug board for the desired channel sequence. Zero scans would test no-load conditions of strain gages and short circuit thermocouples. A calibration scan would shunt a known resistor across one arm of all strain gages and substitute a known voltage for thermocouple inputs. (Reference 8.)

A system of servo instruments would most likely use high level commutation and have the advantage of individual channel calibration. It would also have the advantage of direct monitoring of all channels.

Continuous monitoring with alarms in a low-level commutation system would be difficult to integrate into the acquisition hardware. A special monitor and alarm sub-system would be required to select critical channels, but the additional cost would be relatively small in a large system.

6. Recorders

A recorder is a piece of equipment which preserves the analog signals. This preservation may be only temporary as in the case of a computer memory. In this instance, the computer performs further operations on the stored data and only the final results are preserved. More typically, the raw data are preserved in some manner which utilizes perforating, printing, or magnetic recording on cards or paper or plastic tape. The frequency characteristics of the data of interest dictate the type of recording medium which must be used. In static testing, every piece of recorded data is significant. The date is generally checked by listing and/or plotting. For this type of testing, perforated cards or tape are the most economical. Punched cards provide the maximum capability for sorting and handling data. Cards may be easily edited and repunched, and the handling equipment is the least expensive, and in the widest general use. Card punches, sorters, etc. are readily available and easily maintainable. Punched paper tape is probably the most economical recording material of all, but is not as versatile in handling and editing as cards. Again, the auxiliary equipment; teletype perforators, tape-fed electric typewriters, etc., are readily available and relatively inexpensive to buy or lease. Excellent low- and medium-speed computers for paper tape input and output are available. A complete on-line system for data acquisition, reduction, and presentation can be assembled using paper tape communication throughout. Such a system (Reference 9) is perfectly adequate for static testing.

For the measurement of dynamic conditions, there are two standard techniques of high-speed measurement; analog (oscillograph, strip charts, etc.) and digital. (References 10, 11, and 12.) For a very small number of channels or an infrequently-used system, the analog approach has the economic advantage as well as an immediate graphical output. However, if any reduction is involved on a large amount of data, the conversion to digital records with chart reading equipment is laborious and expensive. For the greatest accuracy and minimum effort, direct digital recording techniques are recommended. In order to accurately analyze transient or higher frequency conditions, the data acquisition system must be able to sample at twice the rate of the highest frequency component. For instance, a transient with a one-second time constant contains frequencies up to 6.28 cps, and this must be sampled at least 12.56 times per second. A fifty-channel system, measuring these conditions must be capable of recording 628 samples per second. Wide band amplifiers and digital magnetic tape recording techniques are indicated. With higher frequency data and the wide band instrumentation involved, the noise problem becomes more severe. However, if high accuracy is needed, the large number of samples can be used to generate a fitted curve to reduce the effect of noise.

To demonstrate why perforated tape is completely impractical for recording dynamic data, let us assume that some scheme such as electric-arc card punching could be developed. These would be the results: the punch would have to operate at 7000 characters per second, the tape would have to be supplied at 58 feet per second, and 10 seconds of recording would generate 580 feet of tape, and require a Flexowriter two hours to list. Therefore, data are recorded on magnetic tape, where the speed is required. The monitoring, handling, and reduction of data at these higher rates are completely foreign to techniques for static data. For instance, in order to be certain of recording a transient, many superfluous samples are recorded before and after the transient. The job of editing is more suited to a computer than a test engineer, and so the raw data equipment is affected. If all raw data in the dynamic tests were to be printed, the many pages of closely typed numbers would be rather meaningless. The only practical use for this volume of data is to enter it into a computer for editing and reduction. The output of reduced-data plots and summarized results is then more digestible. Data reduction of transient data involves much bookkeeping, search for significant data, and generation of fitted curves or auto-correlation techniques to minimize noise. This can be accomplished by a small computer with magnetic tape input or a large general machine such as the IBM 7090.

7. Computers

a. Analog

Accumulated data is seldom useful in the form in which it is collected. The data must be modified or reduced to some common frame of reference and presented in the form of dimensionless coefficients or recognizable engineering units. Nearly all data reduction has been removed from the realm of hand-calculation, and automated by means of suitable electronic computers. The analog computer relies on the analogies between electrical circuit element behavior and various other physical processes. A special purpose analog computer may be designed to handle a specific class of problems. The reduction of force and moment data to dimensionless aerodynamic coefficients from a strain gage balance is one such class. (References 13 and 14.) If a very limited variety of tests are being performed in the facility, the analog computer can provide an excellent solution to the problems of data reduction and presentation. The data may be produced and plotted on-line without the necessity of intermediate storage. Final results are thus presented in an easily digestible form as the test progresses. The basic accuracy of an analog computer is usually somewhat deficient in comparison with the digital computer. However, this accuracy may be compatible with the tunnel flow conditions or other system elements. Analog computer accuracy may be improved by adding circuit components to represent higher order terms, and by specifying elements throughout the system of the highest accuracy and stability.

b. Digital

Digital computers are inherently more versatile than analog computers. With suitable programming, they can handle a much wider variety of problems. Small high speed digital computers may be programmed to control the entire facility operation, as well as collecting, reducing and presenting the data. They may also perform calibration and system checks in their spare time and do general mathematical problems. Although such computers are relatively expensive, they may be shown to be quite economical if they are applied to a wide variety of problems on a heavy duty-cycle. (References 15 and 16.) Large digital computers with their high speeds and vast memories are required for the handling of huge quantities of dynamic and transient measurements. Frequently, small computers are used to prepare the data for rapid input into the big machines. Although the big machines have a high hourly cost, they can handle such a vast quantity of data in such a short period of time that they are more economical than the smaller machines. The output is again on magnetic tape, which is frequently converted by small computers to various other media to operate equipment such as plotters. Wind tunnel facilities cannot afford the sole use of the large computers, but neither do they need computer abilities of this magnitude. Companies which have large digital computers available for other company problems can usually handle their wind tunnel data reduction with about one per cent of their large machine time. (Reference 17.) The variety of tests being performed in most test facilities today requires the versatility of a digital machine. Whereas a few years ago 90% of the tests could be handled with a few force or pressure-integration programs, now there are different and unique types of tests. Data reduction in many cases is quite complicated, requiring sophisticated techniques and the handling of large quantities of data. High speed digital computers are mandatory for these types of problems.

In addition to its versatility, the inherently high accuracy of a digital computer is a powerful asset in the wind tunnel system. A high order of precision may be retained through successive calculations by carrying extra digits and using so-called double precision techniques. Thus, it is possible to not degrade the basic instrument accuracy through computer operations.

This is not true with an analog system where the signal becomes increasingly uncertain as it is successively modified.

8. Listers and Plotters

The accumulated data must be presented in some form from which engineering analyses and decisions can be made. The presentation is usually a tabular listing of numbers or a graphical plot. If the unreduced data is listed or plotted, it is known as a raw data tabulation or a raw data plot. A raw data plot is useful in static testing to monitor the progress of the test and to watch for wild points which may then be repeated before test conditions are changed. Raw data presentations are useful when the final reduced data will not be available for a considerable calendar time after the running of the test. The final data tabulations or plots are sufficient for transient tests where the sheer bulk of the data makes it impractical to derive much information from the raw data. Final data presentation is also sufficient for static tests which are performed on-line. In this case the test progress is monitored in real-time using the final data presentation.

The graphical presentation is more convenient for analysis. Results are easier to visualize and the trends are more apparent when looking at a plot as opposed to a column of figures. If further analysis is required of certain selected areas, it is more convenient to utilize the data tabulations as opposed to attempting to read values from a curve. Maximum accuracy is maintained in the tabulations while further errors would be introduced in attempting to read from the curves.

The listers range from relatively slow-speed equipment such as card-fed or paper tape-fed electric typewriters to ultrahigh speed cathode ray tube page-at-a-time printers. In between are line-at-a-time printers and other high speed listers which operate from magnetic tape. Plotters are of two basic types, continuous, or point plotters. The continuous plotters are usually found in conjunction with an analog computer. The plotting speed of the plotters is similar in range to that of the listers, varying from relatively slow card or tape fed machines up to cathode ray tube plotters. These, like the cathode ray tube listers, are expensive machines and are usually found with a large general purpose digital computer and are not confined simply to wind tunnel usage.

C. System Form

1. Computer Control

The data acquisition system may assume one of several forms. (Reference 18.) If the servicing of many test sites is involved, one of the initial decisions which must be made is whether to provide a data acquisition system at each site or a central data acquisition system. The latter method, while less costly in terms of hardware, can result in expensive delays if the system is not available for the use of a given test site when needed. On the other hand, the installation of many separate systems provides reduced capabilities at each individual test site, yet are quite expensive due to the redundancy of many system components. The central system is definitely advantageous if means can be provided for the maximum use of time-sharing. This means the system for assigning priorities to the various user's requests in a real-time system-scheduling situation can be handled best by a computer. Thus, a single large-capacity system may serve many test facilities if the computer operates the system in an optimum manner in terms of priority of data servicing, channel selection, and sampling rates.

2. Switching Level

All large multiple-input systems use some form of sequential data sampling. This sequencing gives rise to four system forms, depending on whether the signals are switched or sampled at a low signal level or high signal level (i.e., before or after amplification), or whether sequencing is done close to the signal source (in the model or next to the tunnel) or at a remote location such as the central data system. If there are both high level and low level inputs to the system (as is usually the case), a combination of forms may be used. For utmost accuracy, a high level system with an amplifier per channel is required. This circumvents the problems of low-level multiplexing and lengthy transmission of low level signals, with the possibility of introduction of spurious signals. However, this is a very expensive approach for a large system. If requirements permit, a combination system with high-accuracy, high-level channels and somewhat lower accuracy, multiplexed low-level channels presents an attractive economic solution. Careful consideration of the real testing requirements may reveal that the amplifier-per-channel is only required on a limited number of strain gage channels, while a multiplexing system may suffice for most thermocouple channels. Such an approach necessitates a realistic error analysis combined with the best guess as to the types of tests and facility capabilities during the lifetime of the system.

3. System Speed

The form of a data acquisition, reduction and presentation system is highly dependent upon the type of data to be handled. One requirement which has a major impact on the design and form of the data system is the rate at which the data must be acquired. Static testing requiring rather low input rates may utilize card or paper tape equipment. With today's state of the art, dynamic testing and recording of other transient phenomena requiring high input-speeds must be accomplished on magnetic-tape equipment. As mentioned previously, magnetic-tape data processing techniques are quite dissimilar to the techniques employed in handling cards and paper tape. The low speed system will attach a much greater significance to each individual piece of data. The data will be carefully monitored as it is accumulated; frequently by use of raw data listers and plotters. On the other hand, the high speed system will attach very little significance to any individual data point, but will rely on statistical techniques to achieve results. The difference in recording medium and handling philosophy thus affects the system form in terms of control, monitoring, and output.

4. Real-Time Presentation

An important consideration in the design and form of the system is whether an attempt will be made to provide a real-time presentation of the results. The data acquisition system may be greatly simplified if it simply performs as a data logger. The tests may be run "blind" or selected channels of raw data may be monitored. In either case, quantities of data are accumulated which are to be reduced later and presented a "batch at a time". If the batches occur at a short enough time interval in relation to the run rate of the facility, (every ten runs or so whether it's hourly, daily, etc.) a certain amount of test direction and modification may be achieved based on the results of the preceeding runs. If a test program is run and the results are not available until after the conclusion of the program, no advantage may be gained from the knowledge obtained in that test period to modify the direction of the testing.

To approach our ideal system of instantly-available results requires an on-line system. An on-line system may be likened to a production line in which the raw material (transducer signal output) enters one end of a completely automated line emerging at the other end of the line as a finished product (final listed and plotted data). If this data production line is to be truly automated, the subsidiary lines feeding into the main line must also be automated. Calibration data, reduction constants, etc., must be capable of rapid insertion without relying on time-consuming (and error-prone) human calculations. As more elements are added to the on-line system, there are more components involved whose malfunction would prevent the operation of the entire system. For example, in a batch-at-a-time system a plotter malfunction would not prevent the operation of the test facility in the accumulation of data, but in a complete on-line system, tunnel operation might have to await the plotter repair. Therefore, an on-line system tends to involve more redundancy and parallel components than an off-line system. Also, it is necessary to know more about the expected results in order to provide advance specification of the output format including plotting scales and ranges, etc. It is anomalous that the type of tests which most benefit from having on-line final data presentation available is the type of test which is most difficult to prepare for this form of handling. This is the new and different type of testing about which little is known to prepare for the program, but which is most useful to have final results available to help direct the course of the test. On the other hand, a simple, straight-forward type of test which is easy to prepare for on-line processing would generally benefit the least from having final data immediately available.

III. SPECIFICATIONS

A. Accuracy

1. Introduction

The problem of accuracy and its antipode, error, probably have been the subject of engineering discussions since the beginning of scientific thought. Numerous authors have presented their view of the facets of the problem. The purpose of this discussion is to point out specifically the sources of error confronted in the field of wind tunnel data acquisition. A reiteration of work adequately presented by previous authors is not intended. A good general treatment of data accuracy is given in Reference 19.

In the evaluation of the accuracy requirements of a wind tunnel data acquisition system, the accuracy requirements of the final results are the controlling factors. The inaccuracy of these final results can be thought of as possessing several distinct parts. These parts may be either aerodynamic in origin or inherent in the measuring system. It is obvious that the accuracy of the final result cannot be greater than either of the parts, and if both of the parts are assumed to be non-zero, they must be inherently more accurate than the desired final result.

In the consideration of the total accuracy, it is not always possible to consider each part independently because of the nature and magnitude of some aerodynamic parameters and the human ability to measure these parameters as limited by the existing state of the art. Thus, under some circumstances, the measurements to be made must be tailored in some manner to match the type of instruments available to make that measurement. This tailoring must be done in a manner which will not contribute further inaccuracies.

2. Aerodynamic Sources of Error

a. Aerodynamic Similarity

Though not directly related to data accuracy, the problem of aerodynamic similarity must be considered. In almost every case a wind tunnel test is not an end in itself, but the results of the test will be related to some other aerodynamic phenomenon on a larger scale or under differing conditions. Therefore the similarity or degree of similarity between the wind tunnel test and the parent problem represent an amount of certainty on which one can rely in applying the test data toward the solution of the parent problem. Under conditions where there exists considerable similarity-uncertainty, no amount of data accuracy will make the data more reliable than this basic uncertainty.

Basically, the similarity problem can be separated into two categories; that of flow similarity and that of model similarity. In the category of flow similarity are parameters such as Reynolds number, boundary layer growth and similarity, Prandtl and Lewis number, and flow regime. In addition, parameters unique to channel flow, and hence wind tunnel testing, are of importance. Significant among channel flow problems are parameters such as flow angularity and curvature, and spatial gradients of Mach number, pressure, and temperature in the flow field. Time dependent parameters such as free-stream turbulence and fluctuations of stagnation conditions can also become important.

In the category of model similarity model sizing can be an important factor. Available dimensional tolerances may place a limit on the contour accuracy of the model shape thus affecting local pressures and pressure gradients. The addition or exclusion of small model detail can also affect the similarity. The addition of boundary layer trips can adversely affect the flow field in the vicinity of the trips thus cancelling any advantage in maintaining an artificially turbulent boundary layer. Model support problems such as aerodynamic interference and model wake distortion as well as model attitude uncertainty generated by indeterminate support deflections can further complicate the already considerable problem. (References 20 through 22).

It is not within the scope of this work to evaluate analytically the significance of these many sources of uncertainty. Let it suffice to say that experience has shown that, in general, aerodynamic similarity problems can create uncertainties as great as 10%, but generally range between 0.5 and 5.0%.

b. Measurement of Flow Conditions

In making aerodynamic measurements in a wind tunnel, the characteristics of the airflow as well as the pertinent effect of the airflow on the model must be measured. References 23 and 24 present a thorough discussion of this problem. Because of the nature of supersonic channel flow there are several redundant combinations of measurements which can be taken to define the characteristics of the flow. In reality, the dynamic pressure (q) and the Mach number (M) are the most useful quantities but neither can be measured directly. Dynamic pressure is the most significant in terms of data accuracy in that it is normally used in forming the aerodynamic coefficients. Thus anything which tends to make the determination of dynamic pressure inaccurate will tend to make the final results inaccurate.

The determination of Mach number and dynamic pressure usually involve the measurement of two or three pressures in the tunnel. Then the Mach number

$$M = f(P_1, P_2)$$

and

$$q = f(P_{1,2 \text{ or } 3}, M)$$

Figure III-1 [(1)] shows the percentage variation in q per percentage variation in each of the three pressures as caused by the miscalculation of Mach number. The percentage variation in q is equal to the percentage variation in the measured pressure $P_{1,2 \text{ or } 3}$ at a constant Mach number. Figure III-1 is based on the partial differentiation of the several isentropic flow relationships for a perfect gas. The total percentage error in q then is the sum of all the applicable partials, i.e.,:

$$\frac{\partial q}{q} = \left(\frac{\frac{\partial q}{q}}{\frac{\partial P_1}{P_1}}\right)_{M=C}\left(\frac{\partial P_1}{P_1}\right) + \left(\frac{\frac{\partial q}{q}}{\frac{\partial P_1}{P_1}}\right)_{M\neq C}\left(\frac{\partial P_1}{P_1}\right) + \left(\frac{\frac{\partial q}{q}}{\frac{\partial P_2}{P_2}}\right)_{M\neq C}\left(\frac{\partial P_2}{P_2}\right)$$

or as indicated above

$$\frac{\partial q}{q} = 1 + \left(\frac{\frac{\partial q}{q}}{\frac{\partial P_1}{P_1}}\right)_{M\neq C}\left(\frac{\partial P_1}{P_1}\right) + \left(\frac{\frac{\partial q}{q}}{\frac{\partial P_2}{P_2}}\right)_{M\neq C}\left(\frac{\partial P_2}{P_2}\right) \qquad 1)$$

(1) The derivation of the equations used to produce Figure III-1 is given in Appendix A.

3. Measurement Sources of Error

a. Transducers

For the purpose of this report, a transducer is defined as a device which senses a physical condition and translates its finding into a more easily interpretable physical condition. It may, in fact, be a calibrated spring, a column of fluid, a bulb thermometer, or one of several devices which convert force, pressure, temperature, or position into electrical power. The discussion here will be limited to the latter type because of its adaptability to electronic data acquisition.

The selection of a transducer is generally based on the following considerations:

1. Capacity
2. Quality
3. Availability and convenience

The capacity of the transducer, that is, the largest value that it can measure should be no more than 25% greater than the largest value that it will be expected to measure because the accuracy (or quality) tends to depreciate when the capacity is much greater than is needed. The transducer however, should be capable of withstanding a certain amount of overloading if a possibility of overloading exists. If the transducer is not of a fail-safe design, it is possible that the above criteria cannot be met simultaneously, and an arbitrary compromise must be struck. This will result in a sacrifice in accuracy, a risk of damaging the transducer, or both.

The quality of a transducer is a composite of the mechanical quality of the device and the quality of the calibration system used with the device. The mechanical quality is reflected in the hysterisis, linearity and repeatibility characteristics of the transducer, and the response of the transducer to secondary parameters, such as ambient pressure, ambient temperature, time, and previous measurements. The quality of the calibration system is reflected in the calibration techniques and standards, orthogonality of axes systems, and the quality of any sensitivity conversions used.

The availability of a given transducer as well as the convenience in using it is by no means the least important criteria when considered in the non-trivial case. This can best be described by an example. Consider the case where a parameter is to be measured, the value of which is expected to vary between 2 and 9 units. A transducer is available which will measure as many as 10 units. A second transducer is available which will measure only as many as 5 units. The question then is, should the lower range transducer be used to measure the lower units in view of the previous discussion on capacity or is the larger transducer adequate for all measurements? Thus the accuracy requirements must be weighed against the convenience of obtaining a given accuracy.

Figure III-2 is an extension of the data of Figure III-1. By assuming a constant value of P_t for all Mach numbers a new ordinate is formed as

$$\frac{\frac{\partial q}{q}}{\frac{\partial P}{P_{M=1}}} = \left(\frac{\frac{\partial q}{q}}{\frac{\partial P}{P}} \right) \frac{P_{M=1}}{P}$$

where transducer errors are given as a function of the full scale capability of the transducer. If the same transducer is to be used for the complete Mach number range, Figure III-2 shows the percent error in q for 1% error of the full scale capacity of the transducer.

b. Acquisition System

The electrical signals generated by a transducer or a series of transducers are generally collected, converted to some other form and recorded. A device which performs these functions is termed a data acquisition system. This system, which is normally a collection of electronic components, has the capacity to create errors in the final results and hence must be considered in the accuracy of any collected data.

Transducer signals (especially those of strain gages) are predominantly at a very low level. Therefore the first stage of most acquisition systems consist of signal amplifiers. These amplifiers must be of very high quality. They must be extremely linear; that is, the amplification factor must be constant over the complete range of transducer signal levels that are expected. Further, the amplification factor must be virtually independent of time and temperature within some specified limits.

All electronic systems are susceptible to some extent to extraneous electronic noise. In the case of data acquisition systems, electronic noise such as the capacitance discharges and fluctuating magnetic fields of adjacent equipment as well as the system itself tend to be absorbed and interpreted as data signals. These signals introduce errors into the final result and can be either random or periodic in characteristic. If the magnitude of the electronic noise is significantly detrimental to the achievement of the desired accuracies, steps must be taken to either prohibit the introduction of the noise into the system, or to filter out the noise at some point in the acquisition system. In most cases, neither method is completely effective so that often both methods are employed to reduce the noise to some acceptable minimum.

Mechanical noise though similar to electronic noise in effect, is signal noise generated by mechanical means. Usually, this type of noise is caused by an environmental or mechanical phenomenon unique to the experiment, is periodic in character and has a much lower frequency than any periodic electronic noise. In addition, the amplitude of the noise is often significantly large compared to the basic signal level. The filtering of mechanical noise can most easily be done by electronic filtering, but care must be taken so that only the mechanical noise is filtered and the accuracy of the basic signal is not affected.

A significant component in any acquisition system is the data scanner. The function of this component is to sample the signal of one or several transducers at a desired time. The ability of the scanner to sample and transmit the signals from the transducers accurately is indicative of the quality of the scanner.

Data acquisition systems which persent the collected signals in digital form, have as a component of the system an analog-to-digital converter (ADC). The linearity, accuracy and least count of the ADC directly affect the accuracy of the digital data presented. Linearity and accuracy are directly related to the reliability of any number presented. Least count is indicative of the resolving power of the ADC.

The errors introduced by the non-linearity of an acquisition system can be minimized by using a system calibration technique designed to serve that purpose. This method requires that a set of accurately standardized signals be presented to the system in place of the transducer signals. Subsequent comparisons of experimental results with calibration results should provide experimental results essentially free from errors caused by system non-linearity. Such a calibration does not provide any insurance that the data are free from all errors caused by system repeatability and least count. A system calibration can in no way reduce the error caused by repeatability and least count; this can only be done by improvement of the system quality. Statistical evaluations of repeatability and least count errors can be made by numerous calibrations, the differences noted being the result of repeatability and least count errors.

c. Techniques

The most perfect combination of transducers and data acquisition system can be thought to produce intolerable results if improper techniques are employed in using the system and collecting results from it. Improper technique generally results from the violation of the basic limitations of the system, hence the techniques used in acquiring and reducing data must be continually reviewed to assure that they are appropriate for the experimental effort at hand. The vagaries of the human mind permit an almost infinite number of improper techniques to evolve. Two typical examples will be discussed here. Both involve the error of not considering time as a parameter.

The first example is the attempt to make several quasi-steady state measurements in a transient environment when the several measurements are to be related. Most digital data acquisition systems collect data sequentially at a finite scanning rate. Thus, no two measurements are taken at the same time. Let us assume that time (t), and two measurements (m_1, m_2) are to be recorded sequentially at a cyclic frequency (f). Further, at time, t,

$$\begin{aligned} x &= m_1 + m_2 \\ y &= m_1 - m_2 \end{aligned} \qquad 2)$$

Note however that measurements of m_1 and m_2 are not being taken at t but at $t + \frac{1}{3f}$ and $t + \frac{2}{3f}$ respectively. If m_1 and m_2 vary as time progresses, equations 2) must be rewritten such that m_1 and m_2 are taken to be measurements immediately following the time t,

$$x = m_1 = \frac{dm_1}{dt}\left(\frac{1}{3f}\right) + m_2 - \frac{dm_2}{dt}\left(\frac{2}{3f}\right)$$

$$y = m_1 - \frac{dm_1}{dt}\left(\frac{1}{3f}\right) - m_2 + \frac{dm_2}{dt}\left(\frac{2}{3f}\right) \qquad 3)$$

The differences between equations 2) and 3) then represent the errors in x and y if equations 2) are assumed correct.

The second example represents the attempt to make periodic measurements of a basic signal on which is superimposed an oscillatory secondary signal. The problem and approach differ if 1) the absolute value of the signal is desired or 2) if only the time rate of change is desired. Let the total signal (s) be composed of the sum of two signals s_1 and s_2 where s_1 is the basic signal. Let

$$s_2 = k_2 \sin \omega t$$

where t = time

$$\omega = 2 \pi f_1$$

f_1 = arbitrary oscillatory frequency

The basic signal then is

$$s_1 = s - k_2 \sin 2 \pi f_1 t \qquad 4)$$

If t is allowed to be arbitrary it can be seen from equation 4) that the difference between s_1 and s can be as great as k_2. By redefining t as

$$t = \frac{m + c}{f_2}$$

where m = measurement number

c = constant

f_2 = measurement frequency

the error in s can be shown by rewriting equation 4) as

$$\frac{s - s_1}{k_2} = \sin 2 \pi (m + c) \frac{f_1}{f_2} \qquad 5)$$

the worst case being when $c = \frac{1}{2}$. Because m, c, and f_1 are arbitrary, equation 5) cannot be minimized. But if n measurements are taken we find that

$$\frac{s - s_1}{k_2}_{mean} = \frac{\sum_{m=1}^{n} \frac{s-s_1}{k_2}}{n} = \sum_{m=1}^{n} \frac{\sin 2\pi}{n} \frac{(m+\frac{1}{2})}{} \frac{f_1}{f_2} \qquad 6)$$

Inspection of equation 6) shows that the magnitude of $\frac{s-s_1}{k_2}_{mean}$ can be reduced by increasing n and by assuring that f_2 is at least twice as large as f_1. If the purpose of the experiment is to obtain $\Delta s_{1/\Delta t}$, a slightly different approach can be pursued by rewriting equation 4) as

$$s_1 = s - k_2 \sin 2\pi \frac{f_1}{f_2} (m + c)$$

then

$$\frac{\Delta s_1}{\Delta t} = \frac{\Delta s_1}{\Delta m}\frac{\Delta m}{\Delta t} = \frac{\Delta s}{\Delta m}\frac{\Delta m}{\Delta t} - k_3 \left[\sin 2\pi \frac{f_1}{f_2}(m + c + 1) - \sin 2\pi \frac{f_1}{f_2}(m + c)\right] \frac{m}{t} \qquad 7)$$

Note that if $f_1 = nf_2$ when n is some integer, equation 7) becomes

$$\frac{\Delta s_1}{\Delta t} = \frac{\Delta s}{\Delta m}\frac{\Delta m}{\Delta t} \qquad 8)$$

The significance is that if f_1 is some known frequency, a sampling rate of which f_1 is a multiple will permit very accurate determination of the new rate of change of the basic signal.

4. Magnitude of Errors

The errors inherent in any set of data should be made small with respect to the aerodynamic uncertainty so that the total error is as small as possible. In actual practice, aerodynamic uncertainty often can be reduced by inference and re-evaluation after the fact, whereas measurement errors are usually irretrievably buried in the measurement once the measurement has been made.

The total error inherent in any data is the algebraic sum of all the individual errors. The maximum possible error is the arithmetic sum of all the individual errors, that is, the sum of all errors disregarding the sign of each error. The probable error of any measurement is the arithmetic sum of the systematic errors and the random errors.

Systematic errors are those errors inherent in the system and are generally repeated time and again. Random errors are those which appear occasionally and may be either positive or negative in sense and tend to vary in magnitude. Statistical techniques suggest that the probable total random error is equal to the root-sum-square of all the maximum possible random errors. Table III-1 is a list of all of the sources of error discussed in this paper and classified as to type. Four different types of tests are considered (force, pressure, temperature and transient heat transfer). The maximum error magnitudes given are those generally considered acceptable at JPL. Both the maximum possible and the probable error are calculated for comparison.

B. Speed

1. Acquisition

The initial impression is that the required speed of the data acquisition system is somewhat proportional to the run time of the facilities which it serves. In a hotshot or a shock tunnel or shock tube, where run time is measured in milliseconds or microseconds, one desires instrumentation response times in the nanosecond range, and recording in the kilocycle or megacycle range. For this kind of facility, the maximum possible system response is required and even this must be combined with techniques of time expansion on the data tapes. At the other extreme, a continuous facility implies no particular need for the high speed data acquisition, as long as the system keeps up with the tunnel operation. Further analysis will show, however, that it's not so much the facility run time which dictates the required system speed as it is the types of measurements to be made, and the necessary frequency response required to obtain dynamic measurements to a sufficient degree of accuracy. One example of dynamic measurements is transient heat transfer measurements. For example, let us assume that the best definition of the initial heating rate comes from the measurements taken during the first two seconds of warmup after model injection or cooling-shield ejection. Let us further assume that the best definition is acquired by using statistical curve-fitting methods requiring approximately 200 points. These two requirements say that a given thermocouple must be sampled 100 times per second. Further, if we are interested in temparature distribution of, say, 40 or 50 thermocouples, we are already talking about a system requirement for data recording of 4000 to 5000 samples per second. This is not an unusual or overly stringent requirement for a system capable of handling transient heat transfer measurements on a relatively complicated model.

Another dynamic testing requirement is in the measurement of acoustic noise. Some small transducers such as barium titanate crystals do not experience roll-off in their frequency response until up to the 100 KC level or so. Certain types of measurements in this field (boundary layer noise) require very high-speed, sophisticated equipment. In dynamic stability testing it is necessary to obtain several data points during a single cycle. If the model has a natural frequency of, say, 40 cps, and is oscillating $\pm 60°$, to obtain even a few channels of data every few degrees throughout a cycle requires a system range on the order of 5 KC. A measurement of dynamic loads on a strain gage balance will also generate similar requirements. In addition to these dynamic arguments, it may also be shown that system operation may be speeded by having a faster data acquisition rate. For example, a continuous pitching system may be utilized if the data may be accumulated during a sector movement of only a few hundredths of a degree. Since many of the new and interesting problems of today and tomorrow are dynamic problems, a high speed system is a definite asset to the facility. However, before specifying the highest possible scanning rate, it must be remembered that the system accuracy tends to deteriorate with the increased frequency response. This is because many of the sources of system noise are controlled by filtering. The higher system response prevents the use of much of the filtering. A happy compromise might thus be a variable speed system. Again, since circuit design, cabling, and filtering are matched to specific system speeds, speed selection should not be infinitely variable, but consist of discreet system scanning rates. Thus an excellent modern-design could be provided which would cover a slow-speed, highly-accurate mode of operation, coupled with one or more higher-speed, less-accurate modes for dynamic conditions.

2. Reduction and Presentation

If test requirements dictate an on-line system, the reduction and presentation portions of the system must be compatible with the system acquisition rate. This is not to say that the calculation, and listing and plotting rates must proceed at the same speed as the acquisition of data, but the system memory and buffers must accommodate typical data bursts. In any aerodynamic research facility it will be found that the actual data recording time is less than 1 per cent of the total time. One example of a duty cycle of around 1 per cent would be a high-production intermittent tunnel obtaining about 20 seconds of actual data on each run with runs at 30 minute intervals. Another example would be a continuous tunnel performing a transient heat transfer test and obtaining a two-second data burst every three or four minutes (changing model attitude and achieving equilibrium conditions). If the systems in the preceding examples were obtaining data at a 5 KC rate, the reduction and presentations systems would have to operate at about a 50-channel-per-second effective rate to keep up in real time. For very high-speed acquisition systems, the reduction and presentation systems will turn out to be something less than on-line. They will tend to fall behind during testing periods where maximum utilization of the high-speed capabilities of the acquisition system is required. They will catch up on off-shifts, weekends, and during periods of lower system utilization. A study of the expected duty cycle of the facility operation, instrumentation, and test programs defines the speed requirements for the computer, lister, and plotter. The most versatile (expandable) buffer between the acquisition system, computer, and presentation system is magnetic tape. Buffers are necessary between the major system elements to accommodate the different operational rates of the elements, and to allow work to be performed on one element without disabling the entire system.

C. Capacity

The system capacity (or number of channels it must be able to handle at one time) is related both to the type of testing and the physical size of the facilities. A pressure or temperature test where there are many pressure transducers or thermocouples requires more channels than a force test where there are only half-a-dozen strain gages. The larger the facility the more thermocouples or other instrumentation can be built into the model.

Ideally, the data system should be able to accept all the data generated during a given run. Instances may exist where a rare model has so much instrumentation that it would be more economical to repeat the same run, recording different portions of the instrumentation (with some overlap) each time, but such a situation would be unique. Actually, tests will be planned and models designed based on the maximum system capacity. Larger capacity encourages additional instrumentation. Some instrumentation will be found to be superfluous and tests will be more costly than necessary (in terms of both model costs and data analysis) simply because the capacity is there. The specified system capacity should closely match the foreseen requirements during the expected life of the system. Specifications of required system accuracy, speed, capacity, maintainability, versatility, etc., must be based on present or expected future requirements. Just as it was uneconomical to specify too high a system accuracy or too great a system acquisition rate, so also it is uneconomical to specify too large a capacity. A system which handles from 95 to 99 per cent of the requirement is preferable to the system which handles 100 per cent of the requirement, and therefore, by definition, is never completely used. Over the life of the system this overcapacity in equipment, maintenance, space requirements, etc., is very expensive for the amount of utilization. It would also be unreasonable to specify permissible electronic noise to orders of magnitude lower than flow field conditions can ever be determined. To arrive at an appropriate capacity requirement, it is necessary to examine each type of test program expected to be run, and make reasonable assumptions on the number of data channels required to obtain a sensible amount of data.

D. Operation and Maintenance

The desired general philosophy of equipment maintenance and operation should be considered during the specification stage. If an operational and maintenance philosophy can be enunciated, it will aid in the formulation of personnel requirements. This advanced planning will simplify the problems of forming an operational organization. This operational organization should exist in at least a skeleton form during the system specification stage. Although the system user may define the accuracy, speed, and capacity requirements of the system, the system operator should specify the required documentation (drawings and manuals), training program, and system demonstration and check-out procedures.

E. Procedure

System specification consists of several steps. The initial step is taken by the eventual user who assembles his requirements. This user (the test facility engineer) writes this specification in his own language. He uses the simplest approach for describing an automatic data processing system, namely; specifying the system inputs, outputs, and command features. Descriptions of several wind tunnel data processing systems are found in References 25 through 32. Specialized pressure-measuring systems are described in References 33 to 35.

First an analysis is made of the types of test data which must be handled by the user. These quantities are determined by consideration of the present and estimated future testing work. Results of this review as performed by the JPL facility engineers are listed in Table III-2. Consideration of the test results, and potential accuracy of the instrumentation, controlled the input accuracy requirements. Basically the requirements included capacity, (number of facilities, number of analog channels and digital characters per facility) scan rate, signal range, accuracy, stability, repeatability, input amplification, filtering, overload alarm, and channel numbering.

The output requirements are based on what must be seen in the wind tunnel console area in order to properly conduct the test, and what is required in terms of test results. These include the console display, (number of channels, type of plot, oscilloscope, etc.) accuracy, full field digital range, word length, recording mediums, compatibility with existing equipment, computer format, and computer capacity.

The tunnel operator specifys command features in terms of various modes of operation. The basic mode would be called the standard mode, which is a simple data scan. However, since a scanner may be serving several facilities, it is necessary to request the use of a scanner and arrange for some sort of priority system. The "run information" listed in Table III-3 will be recorded just once during the initial scan at the beginning of a run. Succeeding scans of the same run will record the point information listed in Table III-3 and all other pertinent raw data either once, or a selected number of times, or continuously. Continuous scanning could be controlled at will by either internal or external timing. Another operational mode is the counting operation. When a counter sub-system is being used in one facility, it is necessary to automatically sample the counter reading, or readings, at intervals which are determined by the status of the counter storage system. For example, a dynamic stability test requiring a counter in one tunnel would have the counter storage sampled and emptied before it overflows. Another operational mode is the manual stepping mode. It must be possible to manually select any analog channel for digital display and inspection at the scan control station in each wind tunnel console area. This operation must be accomplished independent of the data gathering operation of the standard mode. In this case the display is essentially a digital voltmeter. Other modes include the complete system check-out mode or the system self-calibration mode. The system should re-calibrate itself whenever necessary while not gathering or processing data.

In addition to the system input/output/command features, there are several physical and environmental considerations that must be specified. The height of the equipment must be specified in order to avoid conflict with existing doors and ceilings. Length and depth should be kept minimum consistent with adequate access for maintenance purposes. All maintenance should be accomplished from the front and back of the equipment, and major component failures should be annunciated on the front of the equipment. Control should be accomplished from the front of the equipment. Wiring which connects the equipment should lay in or under the floor in wiring gutters that either already exist or will be provided by the user. Interbuilding connections should be kept below ground level. Attention must be paid to human engineering considerations so the equipment is easy to use and quiet (40 to 50 db or less). Control of the scanning operation and the "run information" in Table III-3 should be accomplished from the model-control console in each wind tunnel area. The operator must have a visual display of the "run information" which he inserts into the system. The new data gathering and processing system should be shaken down and operated satisfactorily as a complete system prior to delivery to the wind tunnel area. Carefully detailed plans for the transition to the new equipment must be provided to minimize the facility down time.

A proposed schedule completes the user-requirements specification. This should include suggested dates for requested proposals, proposal due dates, contract award, system delivery, and completion of transition to the new system.

The next step is for the instrumentation and computer engineers to take this "users requirement" document and convert it into a system specification. The specification is organized to meet two basic requirements. First, it must be easy to find any requirement desired, and second, it must provide an almost automatic check to insure that all important requirements have been included. The systematic procedure for preparing specifications is described in Reference 36.

Finally, with the help of the technical writing consultants of the Specification Department, this develops into an official design specification. It is reviewed (and modified if necessary) by all interested parties, particularly the test facility operator. The design specification for the JPL wind tunnel facility data system is found in Appendix B.

IV. EVALUATION

A. Method

1. Familiarization

A bid evaluation team (six members) consisting of the data system coordinator and engineering representatives from the user organization and the instrumentation and computer and data handling sections was formed. Prior to the release of the request for proposals, the evaluation team attempted to visit all companies which had indicated active interest in submitting a proposal. The team also surveyed current literature on systems and equipment which might prove pertinent to the wind tunnel system. A number of narrow band differential D.C. amplifiers were borrowed and evaluated.

A request for proposals and a bidders package containing specifications, general provisions, statement of work, and proposal instructions were sent to sixteen companies. One week later a bidders conference was held. At the conference an invitation was extended to each bidder to consult with the JPL evaluation team, if additional clarification of the system requirements were desired. No definitive information on specific designs was given.

After the close of the solicitation period, an informal invitation was offered to each company to discuss their proposal. The purposes of the meetings were to insure correct understanding of the proposal, allow each company to offer additional supporting information, and allow the evaluation team an opportunity to assess the company representatives' technical competence.

At least two meetings were held with each company. Typically, the method of computing system accuracy was delineated with the associated assumption discussed. When an arbitrary limit was included (for example, the temperature variation of the room), JPL suggested a value for all companies to use in recalculation of system performance.

At the conclusion of all the conferences, the evaluation team had a thorough understanding of the proposals and had gained a good insight into the companies' competence.

2. Breakdown

The broad purpose of the evaluation is to select a company which can deliver a system which will meet the design objectives with least cost. The design objectives are: 1) Reliability, 2) Accuracy, and 3) Flexibility. An evaluation of only the proposals would not result in valid judgments on the probability of the proposed systems meeting the three design objectives. Therefore, the evaluation was extended to include judgments on the companies' technical capability, ability to produce, and management. An excellent description of a general subcontractor rating system is given in Reference 37.

An arbitrary point scale was chosen and the value for the various categories were adjusted until the relative values were satisfactory. The technical design (proposal) was given 700 points; the company's technical capability (company's ability to satisfactorily solve the problems which will come up during system fabrication), 150 points; the company's physical ability and record for producing the system, 300 points; and the company's management and management policies which are pertinent to the system, 100 points. The company awarded the highest total number of points should be the one which could deliver a system meeting the design objectives with a minimum risk to JPL.

Five companies responded to the request for proposals. The identities of the specific companies will be disguised for the purposes of this report. The intention is to demonstrate the rating process, not how certain companies compared in a particular rating. In fact, if the same companies were to prepare new proposals, and be re-rated, the outcome would probably be considerably different. The companies will be referred to as Companies A, B, C, D, and E. Company A presented two proposals; B, C, and D suggested options within their initial proposals. Three companies informally requested additional time to explore various options. A time extension was granted to all companies. At the end of the proposal period, nine proposals were submitted for consideration.

The systems as proposed offered various hardware capability (an arbitrary choice by the bidder on conditioning equipment load factors). Therefore, the costs could not be compared directly. The costs were adjusted to a common hardware capability, i.e., the same number of filters, power supplies, reference junction boxes, etc. (cf Tables IV-1 and IV-2). The ratio of the technical design evaluation (assumed to be proportional to the delivered system's worth) to the adjusted cost should represent a relative value rating.

3. Proposal Evaluation

The first step in the evaluation was to transform the principal parts of each proposal into a standard form. System block diagrams, analog wiring schematics, digital-data flow charts, and performance tables were made (cf Figures IV-1 through IV-5, Tables IV-3 through IV-6). Team members selected various technical areas for analysis and reported their findings to the group. Discussions followed.

As the relative weights of various categories and the form of the rating sheets were determined, it became evident from the discussions that between the dual proposals from Companies A, B, and D, one was clearly superior from JPL's point of view. Therefore, only one from each of these companies was further evaluated.

Each team member evaluated the remaining proposals individually; equal weight was given to the evaluation of each member for each category judged. The team members are referred to as "a" through "f". The evaluation summary is shown in Table IV-7.

4. Company Evaluation

Company evaluation was based primarily on information contained in the proposals and on insight gained during the conferences with company representatives. Each team member evaluated the companies' technical capabilities (cf Table IV-8), and participated in a joint evaluation of the companies' abilities to produce, and their managements (cf Table IV-9).

B. Results

The results of the evaluation are summarized in Table IV-10. Company B's system was judged superior. As Tables IV-3, IV-4, and IV-5 show, the B system is the only one which meets the accuracy and repeatability specifications for the strain-gage channels, and all but two conditions of the specifications for the thermocouple channels.

This proposal utilizing a common area for both high and low level signal commutation was thus judged the superior system. The guaranteed performance of this system offset the additional cost over the least expensive system.

The primary reason for the superior performance estimate for the B system was the company's thorough understanding of the cause of errors in the system and their willingness to accept the responsibility for delivering a system which met the JPL requirements. They proposed to achieve the estimated performance by designing and constructing the system with extreme care to minimize and distribute the errors to best advantage.

V. CURRENT SYSTEMS

A. Survey of Systems Now in Operation

1. Introduction

In the process of specifying and selecting a new integrated data processing system for the wind tunnel facilities at the Jet Propulsion Laboratory, it became evident that it would be useful to have a better understanding of the capabilities of the existing or proposed equipment at other installations. Consequently, a system-survey was conducted among the major facilities represented by the Supersonic Tunnel Association and the National Aeronautics and Space Administration. Replies were received from 36 of the 39 participating organizations with 32 of the responses describing equipment which could properly be considered a data processing system. A total of 51 systems serving 104 wind tunnels are tabulated. With the exception of the new JPL system, the Northrop system and the McDonnell HIT system, the collected replies represent the status of equipment existing during the survey period of the summer and fall of 1962.

2. Format

The replies are arranged in alphabetical order by facilities. Each facility is assigned a code number-letter for identification on the plots where certain characteristics are displayed. It requires seven pages to tabulate the characteristics of each system. The code numbers and facility name are repeated on each page. The tabulations are arranged with all the first pages together followed by all the second pages and so on. This facilitates examining any given characteristic for all of the systems but does require skipping through the pages to obtain the complete description of a given system.

The information that is tabulated is as follows:

First Pages: I. ACQUISITION SYSTEM

- A. Description
  1. Make and model
  2. Cost (thousands of dollars)
  3. Year of initial operation
  4. Recording medium

B. Capacity

1. Strain gage channels
2. Thermocouple channels
3. Maximum channel capacity at one time
4. Number of single-channel amplifiers
5. Number of commutated channels

Second Pages:

6. Word size

C. Speed (Scanning rate in words per second)

D. Amplifiers

1. Type
2. Number of amplifiers
3. Band pass of filters, if any

E. Commutator

1. Type
2. Signal level

Third Pages:

II. COMPUTER SYSTEM

A. Description

1. Make and model
2. Cost (thousands of dollars)
3. Year of initial operation
4. Input/output medium

B. Capacity

1. Word size
2. Storage capacity
3. Number of registers

C. Speed

1. Cycle time
2. Add and logic time
3. Multiply and divide time

Fourth Pages:

D. Utilization

1. Percent of total usage for wind tunnel data reduction
2. Percent of wind tunnel usage handled in batches
3. Percent of wind tunnel usage on line
4. Typical time from raw data to final results

III. PRESENTATION SYSTEM

A. Raw data

1. Tabulating equipment

2. Plotter

a. Make and model

b. Number of channels

B. Final data

1. Tabulating equipment

2. Plotter

a. Make and model

b. Number of channels

c. Operates on line?

Fifth Pages: IV. SYSTEM AUTOMATION

A. Self-calibration during operation

B. Automated calibration

1. Determination of constants

2. Matrix inversion

C. Completely integrated system

D. Computer control of entire operation

E. Programmed or automated

1. Tunnel start, stabilization

2. Tunnel stop

3. Model pitch or yaw

4. Model roll

5. Model surface deflections

6. Data recording

7. Data reduction

8. Data presentation (raw)

9. Data presentation (final)

Sixth Pages: V. TEST FACILITIES DESCRIPTION

A. Test section dimensions

B. Mach range

C. Run time

D. Maximum stagnation pressure

E. Remarks (maximum stagnation temperature, etc.)

Seventh Pages: VI. EXPLANATIONS AND COMMENTS

The first four pages (Sections I, II, and III) describe the data acquisition, reduction and presentation systems. The fifth pages (Section IV) describe the degree of automation in the combined balance calibration, tunnel operation, and data handling systems. The sixth pages (Section V) describe the physical characteristics of the test facilities served by each data handling system. Finally, the seventh pages (Section VI) present any pertinent explanations or comments relative to each individual system.

3. Discussion

In this tabulation of the characteristics of a selection of data processing systems for wind tunnels there is no mention of system suitability, reliability, maintainability, or accuracy. These are certainly vital system characteristics but, unfortunately, are veritably impossible to assess, particularly by means of any written questionnaire. Even the relatively straightforward questions (like cost, scan-rate, and number of channels) are subject to a wide variety of interpretations and are probably not presented on a completely common base. For these reasons, there is no attempt to form any comparisons among the systems or rate them in any manner. The primary intent of this survey was to disclose where various commercial equipment could be found, so that operational experiences could be discussed with the users. For anyone charged with the responsibility of selecting a new system or purchasing additional system components it would be wise to enter into direct discussion with the users of similar equipment as determined by this survey. The names and addresses of the appropriate contacts at the cooperating facilities are listed in Table V-1.

Generally speaking, the reader of this tabulation would be interested in systems with capabilities which would satisfactorily meet the requirements of his own facilities. That is to say, the operator of a small wind tunnel would not be concerned with a system with hundreds of channels any more than a large facility would be interested in a six-channel system. Also the type of testing (transient heat transfer, etc.) and mode of operation (blowdown vs. continuous) dictates the system speed or scan rate required. Therefore, to separate the spheres of interest the systems have been plotted in Figure V-1 on a log-log plot of maximum number of data channels at one time versus maximum scan rate in words per second. Then an arbitrary division has been made which defines small systems as those with less than 100 channels, and large systems as 100 channels and more; and low-speed systems as those with scan rates of less than 100 words/second, and high-speed systems as 100 words/second and greater. The four categories thus formed of small and large low-speed and high-speed systems are presented in short-form lists in Tables V-2 and V-3. In addition, they are plotted on an age-cost spectrum in Figure V-2 under the same four categories.

A cursory perusal of these Tables and Figures leads to a few general observations. The small, low-speed systems are mostly older systems (three-fourths began operating in the 1954-1959 period) of the digitized Brown readout or analog oscillograph variety. About half are now served by central computing facilities and half have small computers like the Bendix G15. The definition utilized in this survey results in an insufficient number of large low-speed systems to form any general conclusions. The high-speed systems, both small and large, are generally of recent manufacture (over two thirds coming into operation since 1959) and are mostly Consolidated or Beckman systems. In fact, of all the systems represented in this survey and installed since 1960 there are three times as many Beckman 210 systems as any other kind. The small high-speed systems are all served by central computing facilities, as well as about half of the large high-speed systems.

The median costs for the small and large low-speed systems were 50 and 135 thousand dollars respectively. Similarly, the median costs for small and large high-speed systems were 105 and 250 thousand dollars. The average system costs in the four categories are very similar to the median costs (if the two expensive systems at Tullahoma are omitted) being 70 and 98, 120 and 232 thousand dollars respectively.

The presentation systems for both raw and final data include a wide range of plotters with the Electronic Associates, Moseley, and Benson-Lehner models predominating. Some of the large central systems are beginning to use high-speed, high-capacity systems such as the Stromberg-Carlson 4020 CRT printer in conjunction with their IBM 7090 computers.

Concerning the degree of automation involved in these systems, four-fifths of the 51 systems claim automatic data recording. About half of the systems have automatic model pitch and automated data reduction and presentation for both raw and final plots. The percentages of systems claiming various automated features under all or some conditions are shown in Figure V-3. It is evident that computers are not yet controlling wind tunnel systems. Most of the systems (31) claimed 3 to 7 automated features with half of these claiming 4 or 5. Twelve systems have two or less and eight have eight to twelve. It is interesting that these highly automated systems are mostly large company tunnels; i.e., Boeing Supersonic, Cornell Transonic, Douglas Aerophysic Lab., Lockheed-California Division, North American Transonic, Norair, Republic, and JPL (new system).

No.	Facility	I. ACQUISITION SYSTEM								
		Description				Capacity				
						No. of Channels				
		Make and Model	Cost $\$x10^3$	Year of Initial Operation	Recording Medium	Strain Gage	Thermo-couples	Max. at once	Single Channel Amplifiers	Commutated
1a	Aero.Res. Inst. of Sweden	FFA design	40	1957	cards	14 (ea.) x 2	--	14	14	--
1b	Aero.Res. Inst. of Sweden	FFA design	20	1962	paper tape	--	56	56	1	56
2	ARL-Wright Patterson AF Base	Consolidated Syst.Corp.	133	1962	mag.tape	40	40	40	40	40
3a	AEDC, PWT	ARO Syst. Design	1,100	1960	paper tape (mag tape for temp.)	10	100	400 (250 press)	10 S.G. 50 press	100 temp. 250 press.
3b	AEDC, VKF	ERA-1102	Included in computer cost	1954	paper tape	--	--	200	--	452
3c	AEDC, VKF (heat transfer)	Beckman 210	240	1960	mag.tape, Flexowriter	--	(or mv) 100	121	100	121
3d	AEDC, VKF - 100" Hotshot	Plug-in Inst. 20KC Carrier amp. and CEC Oscillographs	70	1962	Photo-sensitive paper (oscillograph)	50	28	50	--	--
3e	AEDC, VKF - 50" Hotshot-1	CEC 20 KC Carrier Amp and CEC Oscillograph	70	1958	Photo-sensitive paper (oscillograph)	50	28	50	50	none
3f	AEDC, VKF - 50" Hotshot-2	VKF design	50	1962	See Comments	--	--	30	24	30

No.	Facility	I. ACQUISITION SYSTEM								
		Description				Capacity				
						No. of Channels				
		Make and Model	Cost $\$ x10^3$	Year of Initial Operation	Recording Medium	Strain Gages	Thermo-couples	Max. at once	Single Channel Amplifiers	Commutated
4a	ASD - Wright Field Supersonic	Taller and Cooper	40	1956	cards	10	--	10	10	none
4b	ASD - Wright Field Hypersonic	CSC Millisadic	110	1959	cards, mag tape, oscillo-graph	50	50	100	1	400
5	Astro, Marquardt Corp.	TMC design	300	1955	cards, mag tape	70	6	100	72	100
6	Ballistic Research Lab	Hanson-Gorrill-Brian	200	1955	paper tape	8	8	8	Servo.	aux. man.
7a	Boeing Transonic	Leeds and Northrup	64	1955	cards	12-3 digit (mv) 3-4 digit (mv)	--	15	--	--
7b	Boeing Supersonic	Giannini	120	1957	cards	14 3 digit	--	14	--	--
7c	Boeing Hypersonic	Boeing-Bristol-Datex	30	1957	cards	10 strip chart	72	82	48 stat. 36 port.	--
7d	Boeing Hot Shot	Boeing-CEC 20 KC, Honeywell 3 KC amps Honeywell visicorders	100	1959	oscillo-graph	48 chan carrier 48 chan for therm-istor ht. trans. meas.	--	48	--	--

No.	Facility	I. ACQUISITION SYSTEM								
		Description				Capacity				
						No. of Channels				
		Make and Model	Cost $\$ x10^3$	Year of Initial Operation	Recording Medium	Strain Gage	Thermo-couples	Max. at once	Single Channel Amplifiers	Commutated
8a	Caltech-JPL (old)	JPL design	150	1957	paper tape	24	99 (LS) 46 (HS)	123	25	99 temp. 100 press.
8b	Caltech-JPL (new)	Astrodata	360	1963	mag. tape	25 to 40	200	258	25 to 40	200
9	Chance Vought Corp.	Beckman	150	1958	mag. tape	120	120	120	20	100
10a	Cornell Transonic	Cornell digital, CEC analog	120	1954	cards, 405 printer	30 static, 16 dynamic	20/ i.c 9/ c.a	46 (stat. and dyn)	46	828 (pres)
10b	Cornell W. S. Hypersonic	CEC	--	1962	Oscillograph paper	70	70	70	70	none
11	David Taylor (USN)	Beckman 210	250	1960	paper and mag. tape	50	50	50	50	50
12	Douglas Santa Monica	Datex	110	1958	cards	16	16	16	16	0
13a	GD-Convair Low Speed	External balance - Tate Emery Internal balance - Convair	ex. 50 in. 30	1946 1961	cards	8 24 (notes)	10 chan. strip chart	434 50, SG 384 pres.	10 - 1 to 1000 gain	50 by 10 384 by 8
13b	GD-Convair High Speed	CEC Millisadic	150	1958	cards, mag. tape	125	125	125	25	40

No.	Facility	I. ACQUISITION SYSTEM								
		Description				Capacity				
						No. of Channels				
		Make and Model	Cost $\$ x10^3$	Year of Initial Operation	Recording Medium	Strain Gage	Thermo-couples	Max. at once	Single Channel Amplifiers	Commutated
14a	Grumman Subsonic	Grumman	15	1962	paper tape	10	--	25	1	25
14b	Grumman Supersonic	CEC 5-123 osc. w/ data flash	10	1961	photo. paper	36	30	52	--	--
14c	Grumman Press. System	Fischer Porter MPRS	40.8	1957	paper tape	(See comments)		150		
15a	Lockheed-Calif.	Beckman 210	250	1960	mag. tape.	120	120	120	20	100
15b	Lockheed-MSC	Mod. 1108 Visicorder, 5 Tektronix 530 scopes	15	1960	Oscillo-graph paper	12	6	18	18	0
16	Mass.Inst Tech.	MIT design	150	1957	paper tape	6	40	46	None	46
17a	McDonnell PSWT	Consol. Microsadic MKI	290	1959	mag. tape	125	24	125	25	125
17b	McDonnell HIT	Minneapolis-Honneywell Loop Tape Recorder	110	Aug. 1963 target dt	FM tape	50	50	50 data and 10 identification	50	0
18a	NAE-Canada high speed	Minneapolis-Honeywell	50	1957	cards	10	--	10	--	--
18b	NAE-Canada Low speed	Datex and Donner Scientific	60	1960	paper tape	18	--	27	--	--

No.	Facility	I. ACQUISITION SYSTEM Description Make and Model	Cost $\$x10^3$	Year of Initial Operation	Recording Medium	Capacity No. of Channels Strain Gage	Thermo-couples	Max. at once	Single Channel Amplifiers	Commutated
19a	NASA - Ames Unitary	Beckman 210	120/sys.	1962	paper tape	300	300	300	6	300
19b	NASA - Ames 3.5 HWT	Beckman 210	375	1960	mag. tape	50	40	100 (400 w/low level comm)	90	100
20a	NASA - Langley Unitary	NASA Langley	165	1961	paper tape	24	0	40	24	40
20b	NASA - Langley Central Data	Beckman 210	435	1960	mag. tape	220	220	220 analog, 20 digital	220	20 dig. gated 220 analog
21	NASA - Marshall	CEC Sadic	50	1957	cards	6	6	6	6	0
22	Naval Ord Lab	Epsco	250	1961	mag. tape	100 (6 with int shunts and bal. cont.)	100	102	12	102
23	NAA - Columbus	Beckman 5770-9	200	1959	mag. tape	80	4	80	30	80
24	NAA-Tri-sonic	NAA-Auto-netics	100	1957	mag. tape	120	120	120	20	120

No.	Facility	I. ACQUISITION SYSTEM								
		Description				Capacity				
						No. of Channels				
		Make and Model	Cost $\$x10^3$	Year of Initial Operation	Recording Medium	Strain Gage	Thermo-couples	Max. at once	Single Channel Amplifiers	Commutated
25	Northrop Norair	Astrodata (custom)	160	1963	mag. tape	150	100	250- 100 from HS, 100 from SS, 50 from low speed tunnels	6 plus any quantity up to 250	(variable) 0-250 as required for sampling speed
26	Ohio State University	OSU	20	1956	direct, analog	12	18	30	12	0
27	Republic	Systron-Donner/ 60-10	70	1962	mag. tape	30	30	100	1	100
28a	Sandia Hypersonic	Bristol Dynamaster and Datex enc.	45	1959	cards	13	13	13	13	0
28b	Sandia Trisonic	Strip Chart recording and Datex	50	1956	cards	9	1	10	10	0
29a	United Subsonic	Epsco	300	1958	mag. tape (digital)	20	200 sub multiplex)	20	20	200 (temp or press)
29b	United Transonic Supersonic Hypersonic	Giannini Datex 14335	40	1955	cards	12	--	12	12	--

		I. (Cont.) ACQUISITION SYSTEM						
				Amplifier			Commutator	
No.	Facility	Word Size	Scan Rate words/sec.	Type	No.	Filter, Band Pass	Type	Signal Level
1a	Aero.Res. Inst. of Sweden	3	14	Leeds Northrop Speedomax chopped DC input servo amp	14	no	--	--
1b	Aero.Res. Inst. of Sweden	3.	50	Offner 491	1	yes	solid state	± 5 volt
2	ARL-Wright Patterson AF Base	4/3 digit	7500/ 10,000	Sanborn chopper stab. DC	40	no	yes	high
3a	AEDC, PWT	15 bit binary 4 dec dig + sign	20 temp to 3000 words	SG-Beckman Fitgo; press. CEC Type 1-126	10 SG 50 press.	no	Press-merc. wetted relay; Temp-solid state	high
3b	AEDC, VKF	15 binary bit	20	(See comments)			relay	high
3c	AEDC, VKF (heat transfer)	4 dig (BDC) + sign	2400	Beckman Fitgo	100	yes	solid state	high
3d	AEDC, VKF - 100" Hotshot 1			Carrier amp/ modulator for DC input	50	200 cps galvo		
3e	AEDC, VKF - 50" Hotshot 1			Carrier amp/ modulator for DC input	50	200 cps galvo	no	
3f	AEDC, VKF - 50" Hotshot 2	8 binary bits	10,000	VKF design	24	DC- 200 cps	Wiancko Epsco A to D converter	high
4a	ASD - Wright Field Supersonic	4 dec. dig.	Sim. NA Readout	Brown Chopped DC input, AC servo	10	no	none	--
4b	ASD - Wright Field Hypersonic	3 dig. BCD	400	DC, AC Carrier	50,50	no	yes	500 mv.

No.	Facility	I. (Cont.) ACQUISITION SYSTEM						
				Amplifier			Commutator	
		Word Size	Scan Rate words/sec.	Type	No.	Filter, Band Pass	Type	Signal Level
5	Astro, Marquardt Corp.	3 digit + time + ident.	400 chann/sec.	AC carrier, demod. output and Brown	72 AC, 6 Brown	no	Relay matrix	0.5V
6	Ballistic Research Lab.	± 9999	0.9	MH 40 x 10^6	8	no. Servo pass < 10 cyc.	Manual used occasionally	low
7a	Boeing Transonic	3 digits	1.0	Leeds and Northrop strip chart	--	Fco 1/4 to 3/4, 12 db/oct.	None	--
7b	Boeing Supersoni	3 digits	1.66 scans/sec.	Bristol	--	(strip chart recorders)	No	--
7c	Boeing Hypersoni	3 digits	1.66 scans/sec.	Bristol	--	(strip chart)	No	--
7d	Boeing Hot Shot			CEC 20 KC Carrier Honeywell 3KC Carrier	24 24	40-4000 cps/24 db/oct.	No	--
8a	Caltceh-JPL (old)	6	6	Chopp. DC,AC servo	25	No (1 cycle available)	Stepping switch	high
8b	Caltech-JPL (new)	13 binary bit	5000	Astrodata TDA 880 Astrodata TDA 885	36 10		Solid state multiplexer	low
9	Chance Vought Corp.	12 BCD + sign	1000 (see comments)	DC Chop.Stab. 400 cps	20	yes, no	Electric switch	high
10a	Cornell Transonic	4 digits	26	CAL static, CEC dyn.	30, 16	CAL	.5 to 18 sec. press. scan and CAL	low
11	David Taylor (USN)	Polarity + 4 digits	533	15 DC Fitgo	50	0-5 cps	Transister switch	high
12	Douglas Santa Monica	3	1.4	Leeds and Northrop	16	no, 1/2 cyc. low pass avail.	No	--

No.	Facility	I. (Cont.) ACQUISITION SYSTEM Word Size	Scan Rate words sec.	Amplifier Type	No.	Filter, Band Pass	Commutator Type	Signal Level
13a	GD-Convair Low Speed	5 digit word	10 words/ sec.	Kintel DC Mod. 114	10	1 to 2 cycles	Stepping switch	low
13b	GD-Convair High Speed	XXX (BCD)	400	DC (NEFF Type 1000)	25	low (RC .05 to 1 sec)	CEC	0.5 volt (high)
14a	Grumman Subsonic	12 digit	4	High gain, diff. input		No	Stepping switch	low
14b	Grumman Supersonic	--	--	DC	--	Yes	--	low
14c	Grumman Press. Inst.	--	--	--	--	--	--	--
15a	Lockheed California	6 digit	7000	Beckman Fitgo	20	6 or 800	20 at 7000/ sec/ 100 at 200/sec	high transistors; low - step switch
15b	Lockheed MSC	Analog	--	CEC Carrier	1-127		No	
16	Mass.Inst of Tech.	3 digits	--	Brown	6	No	Shaft encoder	low-milivolt
17a	McDonnell PSWT	6	1572 max.	Kintel 114 ACA	25	10 cyc. on pre-amp select low pass 1 - 6	Relay	25 channel sub-comm. 5 time share groups
17b	McDonnell HIT	Analog	Analog	Plug In SCAS-1004-R	50	low pass 70 cps on 6 channels	analog	analog

No.	Facility	I. (Cont.) ACQUISITION SYSTEM		Amplifier			Commutator	
		Word Size	Scan Rate words/sec.	Type	No.	Filter, Band Pass	Type	Signal Level
18a	NAE-Canada High speed	3 DD	12	--	--	0-20 cps	No	--
18b	NAE-Canada Low speed	3 - 5 DD	3 to 5	--	--	--	--	--
19a	NASA - Ames Unitary	5 digit	10	Beckman Fitgo DC Chopper Stabilized	6	0-5 cps	Oil immersed stepper	low
19b	NASA - Ames 3.5 HWT	5 or 6 digit	2500	Fitgo DC Chopper Stab.	90	0-2, 0-15, 0-50	Mechanical	low
20a	NASA - Langley Unitary	Variable	60 char/sec.	Low level, chopper, stabilized vac. tube.	24	0-5 cps	Electro-mechanical	high
20b	NASA - Langley Central Data	4 BCD digit ± sign	2400	Beckman Fitgo	220	0-4 cps	Solid state	high
21	NASA - Marshall	Sign + 3 dec. digits	4	CEC 1-121	6	variable	No	--
22	Naval Ord Lab	Sign + 3 digits	12.5, 250, or 5000	Mod. Offner 190's + Epsco amp	12	2 or 40 cycles	Crossbar Electronic	low high
23	NAA - Columbus	4	800	Operational, Offner 190 diff. input	30 oper. 30 off	1, 2, 5, 10, 20, 50 as selected	Electric switching	high
24	NAA - Trisonic	0 to 2047 (11 bits)	3600	Doelcam 2HLA-4	20	12 cyc	Norwood rotating Mercury jet	low 80 mv.
25	Northrop Norair	4 BCD digit ± sign	1000-normal	Astrodata Mod. 875	6 norm. 250 max.	variable	Field-effect transistor	low 0-80 mv.

		I. (Cont.) ACQUISITION SYSTEM						
				Amplifier			Commutator	
No.	Facility	Word Size	Scan Rate words/sec.	Type	No.	Filter, Band Pass	Type	Signal Level
26	Ohio State University	--	--	DC - Doelcam 2HLA-4	--	Yes	No	--
27	Republic	6	100	DC	1	No, 3.0 KC	Relays	low
28a	Sandia Hypersonic	3 digit	1.66	incl. in recorder	13	No	No	--
28b	Sandia Trisonic	3 digit	1.66	Built into recorders	10 + 4 ch CEC	No	No	--
29a	United Subsonic	16 bit	11000	Low level diff.	20	variable 1 cps to ∞	Low speed mechanical	low
29b	United Transonic Supersonic Hypersonic	3 or 4 digits (note)	20 decimal (note)	Bristol	12	1, 3, 10 cyc. low pass	Giannini C109, C102	high

No.	Facility	II. COMPUTER SYSTEM Description Make and Model	Cost $ x10^3	Year of Initial Operation	Input/ Output Medium	Capacity Word Size	Capacity	Number of Registers	Speed Cycle Time u sec	Add/ Logic Time u sec	Mult./ Divide Time u sec
1a	Aero. Res. Inst. of Sweden	IBM 1620	24/yr	1961	Keyboard, cards	variable + sign	20,000 digits	--	--	--	--
1b	Aero. Res. Inst. of Sweden	--	--	--	--	--	--	--	--	--	--
2	ARL-Wright Patterson AF Base	IBM 7090	Central Faci-lities	--	--	--	--	--	--	--	--
3a	AEDC, PWT	ERA 1102	500	1957	Paper tape, flexowriter, plotter	24 binary bits	16,384	3	64 to 8000	24	256/ 320
3b	AEDC, VKF	ERA 1102	325	1954	Paper tape	24 bit	8192 words	3	8,500	24	40
3c	AEDC, VKF (heat transfer)	IBM 7070	Leased	1960	Mag. tape, paper tape, cards	10 dig.	10,000 words	3 to 5	6	250	1000
4a	ASD - Wright Fld Supersonic	IBM 7090	Shared w/all ASD	--	--	--	--	--	--	--	--
4b	ASD - Wright Fld Hypersonic	IBM 7090	Shared w/all ASD	--	--	--	--	--	--	--	--
5	Astro Marquardt	ALWAC III E	125	in pro-cess	Cards, tape, flexowriter	16 hex char + sign	8192	4	--	--	--
6	Ballistic Research Lab	BRL ESC	3,000	1962	Mag tape, cards	72 bits	4096 initial 24576 on order 65536 ulti-mate	4	1.5	5	25 65
7a	Boeing Transonic	IBM 7090	Central Faci-lity	--	--	--	--	--	--	--	--

		II. COMPUTER SYSTEM										
		Description				Capacity			Speed			
No.	Facility	Make and Model	Cost $ $x10^3$	Year of Initial Operation	Input/ Output Medium	Word Size	Capacity	Number of Registers	Cycle Time u sec	Add/ Logic Time u sec	Mult./ Divide Time u sec
7b	Boeing Supersonic	IBM 7090	--	Central Facility	--	--	--	--	--	--	--
7c	Boeing Hypersonic	See Comments	--	Central Facility	--	--	--	--	--	--	--
7d	Boeing Hotshot	See Comments	--	Central Facility	--	--	--	--	--	--	--
8a	Caltech - JPL (old)	Burroughs 205	125	1954	Keyboard, paper tape	10 BCD + sign	4080	2	800	200	2
8b	Caltech - JPL (new)	PDP-1	360	1963	Mag. tape, paper tape	18 bin. bits	4096 (+4096)	2	5	10	40
9	Chance Vought Corp.	Beckman EASE Analog	20	1958	Dig. mag. tape/5-11x 17 plotters	--	--	--	--	--	--
10a	Cornell Transonic	Burroughs 204	250	1956	Keyboard, cards, 407 printer.	10 BCD + sign	4080	3	800	200	2000
11a	David Taylor	Univac I	.040/ hr.	1960	Mag. tape	12 char	1000 words	10	Random access	525	2150/ 3890
11b	David Taylor	IBM 7090	.550/ hr.	--	Mag. tape	36 bits	32,768 words	5	2.4	4.8	38/48
11c	David Taylor	Rem. Rand Larc II	.245/ hr.	1962	Mag. tape	12 char	32,000 words	78 high speed	4	4	8/32.2
12	Douglas Santa Monica	IBM 1620	3.595/ mo.	1961	Keyboard, cards	Variable	60,000 digits	None	20	variable	variable
13a	GD-Convair Low Speed	IBM 1620	Leased 2.500/	1961	Cards, keyboard	Variable decimal	20,000 dec. digits	200 μs	40	1000	2500

		II. COMPUTER SYSTEM									
		Description				Capacity			Speed		
No.	Facility	Make and Model	Cost $ $x10^3$	Year of Initial Operation	Input/ Output Medium	Word Size	Capacity	Number of Registers	Cycle Time u sec	Add/ Logic Time u sec	Mult./ Divide Time u sec
13b	GD-Convair High speed	IBM 1401 Mod. B	5.135 /mo.	1962	Cards	Variable	16 K char.	--	11.5	vari- able	vari- able
14a	Grumman Subsonic	IBM 7090	Cen- tral		--	--	--	--	--	--	--
14b	Grumman Supersonic	IBM 7090	Cen- tral		--	--	--	--	--	--	--
14c	Grumman Press.Inst.	IBM 7090	Cen- tral		--	12 bit cyclic	4080	--	--	--	--
15a	Lockheed- California	IBM 1401	Rental	1960	Mag. tape, cards, printer	Variable	4000 char.	3	0	253	3500
15b	Lockheed- MSC	Burroughs 220		1961	cards/ printer	10 dig. + sign	10,000	2	400	200	2000
16	Mass.Inst. of Tech.	Bendix G15A	50	1957	Keyboard, paper tape	29 bits + sign	2000 words	3	--	--	--
17a	McDonnell PSWT	IBM 7090	.112/ hr. for W.T.	1960	Mag. tape, cards	35 bin- ary + sign	32,768	2	2.8	2 cycles	11.6/ 14.0 cycles
18a	NAE- Canada High Speed	Bendix G15	50	1956	Paper tape (100 char/ sec)	--	--	--	--	--	--
18b	NAE- Canada Low Speed	IBM 1620	Rental	1962	Cards (100 char/sec)	variable	20,000 char.	--	--	--	--
19a	NASA - Ames Unitary	MH H-800	36/mo.	1962	Cards, paper tape, mag. tape	48 bits	16,384	256	6	24	150 312
19b	NASA - Ames HWT	IBM 704 or 7090	--	--	--	--	--	--	--	--	--

No.	Facility	II. COMPUTER SYSTEM									
		Description				Capacity			Speed		
		Make and Model	Cost $ $x10^3$	Year of Initial Operation	Input/ Output Medium	Word Size	Capacity	Number of Registers	Cycle Time µ sec	Add/ Logic Time µ sec	Mult./ Divide Time µ sec
20a	NASA - Langley Unitary	IBM 1620	40/yr	1961	Paper tape cards	Instruct 12, data variable	40,000 char.	8	20	560/ 200	4960/ 16860
20b	NASA - Langley Central Data	IBM 7070	23.200 /mo.	1961	Mag. tape	10 numeric dig. + sign	9990	3	6	60 36	228 1800
21	NASA - Marshall	Bendix G-15	2.500/ mo.	1958	Card, paper tape, mag. tape	28 bit	2160 drum + tape	4	29,000	540	<15000
22	Naval Ord Lab.	IBM 7090 and NOL Analog			--	--	--	--	--	--	--
23	NAA- Columbus	IBM 709	55/mo	1961	Mag. tape	6 BCD char.	32,768	2	12	24	40 (max)
24	NAA- Trisonic	ALWAC III E	200 (incl. plotter)	1957	Mag. tape, cards	33 bits incl. sign	128 words working 4096 words, main	3	1 ms working storage 104 ms from main memory	1 ms	17 ms
25	Northrop	Central 7090 and/or 1620 on-line	5/mo.	1963	Mag. tape	36 bits	32,768 (max)	3	1	2	14 (max)
26	Ohio State University	Electronic Assoc.	60	1956	Electrical signals	--	--	--	--	--	--
27	Republic	Central 7090			--	--	--	--	--	--	--
28a, b	Sandia Hypersonic and Trisonic	CDC 1604	Central	1961	Mag. tape	--	--	--	--	--	--

		II. COMPUTER SYSTEM									
		Description				Capacity			Speed		
No.	Facility	Make and Model	Cost $ x10³	Year of Initial Operation	Input/ Output Medium	Word Size	Capacity	Number of Registers	Cycle Time μ sec	Add/ Logic Time μ sec	Mult./ Divide Time μ sec
29a	United Subsonic	IBM 7090	Lease	1961	Mag. tape	36 bits	32,768	3	1	2.1	2 to 14
29b	United Transonic Supersonic Hypersonic	IBM 7090 Philco Transac	Lease	--	Cards, mag tape	36 bits	32,768	3	1	2.1	2 to 14

No.	Facility	II. (cont.) Utilization: % for Wind Tunnel	Batch at a Time %	On Line %	Typical Time: Raw Data to Final Results	III. PRESENTATION SYSTEM — Raw Data: Tabulating Equipment	Raw Data Plotter: Make and Model	Raw Data Plotter: Number Channels	Final Data: Tabulating Equipment	Final Data Plotter: Make and Model	Final Data Plotter: Number Channels	Final Data Plotter: On Line
1a	Aero. Res Inst. of Sweden	90	100	0	24 hrs.	—	Speedomax	14	IBM 870	D-Mac 1018 EA 3200	1,2	No
1b	Aero. Res Inst. of Sweden					Paper tape output						
3a	AEDC, PWT	75	46	54	20 sec to 1 min.	No	EA 205	10	5 flexo-writers, teletype punch	Gerber Scientific 501B Moseley 4D	4	Yes
3b	AEDC, VKF	100	100	0	—	Flexo-writer	Gerber 501	3-9	Flexo-writer	Gerber 501	3-9	No
3c	AEDC, VKF (heat transfer)	60	100	0	1-8 hrs.	IBM 1401	Gen. Dyn. Sys. w/Gerber plotters	6	IBM 1401	Gen. Dyn. Sys. w/Gerber plotters	6	No
4a	ASD - Wright Field Supersonic	—	100	0	—	IBM 402	BL Mod G	7	IBM 1401	BL Mod E	1	No
4b	ASD - Wright Field Hypersonic	—	100	0	—	IBM 402	BL Mod G	7	IBM 1401	BL Mod E	1	No
5	Astro, Marquardt Corp.	100	95	5	15 min	Flexo-writer	Librascope	12	Flexo-writer	Librascope	12	No
6	Ballistics Research Lab	0.1-0.3	100	0	4-48 hrs.	Flexo-writer	Hanson-Gorrill - Brian. Electro Inst. 400	6,7	IBM 407	EAI 3300, 3440	1	No

		II. (cont.)				III. PRESENTATION SYSTEM						
		Utilization				Raw Data			Final Data			
							Plotter			Plotter		
No.	Facility	% for Wind Tunnel	Batch at a Time %	On Line %	Typical Time: Raw Data to Final Results	Tabulating Equipment	Make and Model	Number Channels	Tabulating Equipment	Make and Model	Number Channels	On Line
7a	Boeing Transonic	1.6%	100	0	8 hrs	IBM 407	Moseley No. 2 X-Y	4	IBM 1401 in central facility	None		
7b	Boeing Supersonic	for all tunnels	100	0	8 hrs	IBM 402	EAI 1100 1100 X-Y	4		None		
7c	Boeing Hypersonic		100	0	24 hrs.		Moseley No. 2 X-Y	2		None		
7d	Boeing Hot Shot		100	0	48 hrs.		None			None		
8a	Caltech-JPL (old)	100	35	65	10 sec (on line)	Tele-reader, Flexowriter	JPL Design	24	Tel. read Flexowriter	JPL Design SC 4020	9,7	No
8b	Caltech-JPL (new)	100	100 Initially		2 Hrs.	Tele-reader Flexowriter	JPL Design	24	IBM 1401 in Central Facility	Stromberg Carlson 4020	--	No
9	Chance Vought Corp.	100	0	100	0	IBM 526	Beckman	10	IBM tab runoff from 7090	EA vari plotter	1	No
10a	Cornell Transonic	90	20	80	30 sec.	IBM 405, IBM 523	No	—	IBM 407, 528	Pace Data-plotter	—	—
11a	David Taylor	5	100	0	one hr.	Flexowriter Unityper, Uni-printer	None	—	Unityper, Uniprinter	None	—	No
11b	David Taylor	2	100	0	one hr.	Flexowriter Uni-printer	None	—	IBM 1401	SC 4020	—	No

No.	Facility	II. (cont.) Utilization % for Wind Tunnel	Batch at a Time %	On Line %	Typical Time: Raw Data to Final Results	III. PRESENTATION SYSTEM Raw Data Tabulating Equipment	Raw Data Plotter Make and Model	Raw Data Plotter Number Channels	Final Data Tabulating Equipment	Final Data Plotter Make and Model	Final Data Plotter Number Channels	Final Data Plotter On Line
11c	David Taylor	2	100	0	one hr.	Flexo-writer Uni-printer	None	—	High Speed printer	None	—	No
12	Douglas Sta. Monica	100	100	0	20 sec.	IBM 407	None	—	IBM 407	B-1 Mod.H	1	No
13a	GD-Convair Low Speed	30	20 single run, 80 batch	0	20 min. single run; 1 hour batch	IBM 405	Manual	—	IBM 407	EA 3033B	X-Y 12 card fields	No
13b	GD-Convair High Speed	100	30	70	15 min	1403 printer	EA Data-plotter	1	1403 printer	EA Data-plotter	1	No
14a	Grumman Subsonic	small	100	0						EA 3033-A-2	1	No
14b	Grumman Supersonic	small	100	0						EA 3033-A-2	1	No
14c	Grumman Press. Inst.	small	100	0		Flexo-writer	None			EA 3033-A-2	1	No
15a	Lockheed-Calif.	100	100	0	—	IBM 1403 line printer	MH mod. 1102	20	IBM 1403	EA 3033B-2	2	No
15b	Lockheed-MSC	0.1	all	0	24 hrs,	analog records	Manual	all	analog records	Manual	all	—
16	MIT	50	20	80	30 sec	IBM type-writer	None	—	Flexo-writer tape punch	Moseley	4	Yes

		II. (cont.)				III. PRESENTATION SYSTEM						
		Utilization				Raw Data			Final Data			
							Plotter			Plotter		
No.	Facility	% for Wind Tunnel	Batch at a Time %	On Line %	Typical Time: Raw Data to Final Results	Tabulating Equipment	Make and Model	Number Channels	Tabulating Equipment	Make and Model	Number Channels	On Line
17a	McDonnell PWST	10	--	remote location	15 min.	IBM 1401	IBM 1401	25	IBM 1401	Benson-Lehner Model J	6	No
17b	McDonnell HIT	1	--	remote location	45 min.	IBM 1401	IBM 1401	25	IBM 1401	Benson-Lehner Model J	1	No
18a	NAE-Canada High Speed						Minn-Honeywell	10	IBM Serv. Bureau	EAI 3033C	1	No
18b	NAE-Canada High Speed	100			30 min.	IBM typewriter	EAI 3033C	1	IBM typewriter	EAI 3033C	1	No
19a	NASA-Ames Unitary	99	90	10	10-15 sec.	Monroe Datalog	No	--	Flexo-writer	EA 3033-1A	6 to 8	Yes
19b	NASA - Ames HWT					Flexo-writer, Oscillo-graph	No	--				
20a	NASA - Langley Unitary	20	0	100	25 sec.	IBM 416	None	--	Flexo-writer	EA 11"x17"	12	Yes
20b	NASA - Langley Central Data	25	100	0	20 min. reel of data	Flexo-writer IBM 1401	IBM 1401, EA	1 ea.	IBM 1401	EA	1	No

		II. (cont.) Utilization				III. PRESENTATION SYSTEM Raw Data			Final Data			
							Plotter			Plotter		
No.	Facility	% for Wind Tunnel	Batch at a Time %	On Line %	Typical Time: Raw Data to Final Results	Tabulating Equipment	Make and Model	Number Channels	Tabulating Equipment	Make and Model	Number Channels	On Line
21	NASA - Marshall	60	100	0	<1 hr (avg.) <1 min (spec.)	IBM 870	EA 1100	1	IBM 407	B-L Mod J	1	No
22	Naval Ord. Lab.				Analog on line, IBM 1 day	IBM 1401	Moseley XY, bar-graph CRO--on line Elect.Ass.--off line	6	IBM 1401	EAI 3440 Dataplotter	6	No
23	NAA - Columbus	3	100	0	24 hrs.	IBM 1401	Moseley 4S	6	IBM 1401	None	--	--
24	NAA - Trisonic	100	100	0	30 min.	IBM 407, Flexo-writer	2 Moseley Autographs 2 axis recorders	2 ea.	IBM 407	Benson-Lehner Mod. J w/ IBM 523 card reader	All computed parameters	No
25	Northrop Norair	100	100	50	2-3 min.	IBM 418	EA	6	IBM 418	EA	6	Yes
26	Ohio State University	100	20	80	on line	Tape printer	EA 1100	6	Tape printer	EA 1100	6	Yes
27	Republic	Small	100	0								
28a, b	Sandia Hypersonic and Trisonic	<1	100	0	24 hrs.	Flexo-writer	No	--	CDC 1612 HS printer	Vari-plotter	1	No

		II. (cont.) Utilization				III. PRESENTATION SYSTEM							
						Raw Data			Final Data				
							Plotter			Plotter			
No.	Facility	% for Wind Tunnel	Batch at a Time %	On Line %	Typical Time: Raw Data to Final Results	Tabulating Equipment	Make and Model	Number Channels	Tabulating Equipment	Make and Model	Number Channels	On Line
29a	United Subsonic	<1	100	0	15 min. up	--	No	--	IBM 7090 off line printer	None	--	--
29b	United Trans. Super-sonic Hyper-sonic	1	100	0	15 min. up	Cards & print out	Bristol Dynamaster 560 Strip Charts	12	Print out, cards	Moseley X-Y	1	No

No.	Facility	IV. SYSTEM AUTOMATION													
		Self calibration during operation	Constant Determination	Matrix Inversion	Complete System Integration	Computer Control	Tunnel Start	Tunnel Stop	Model pitch/yaw	Model Roll	Surface Deflection	Data Recording	Data Reduction	Data Presentation (raw)	Data Presentation (final)
1a	Aero. Res. Inst. of Sweden							X	X			X		X	
1b	Aero. Res. Inst. of Sweden														
2	ARL-Wright Patterson AF Base	O							X	X		X	X	X	O
3a	AEDC, PWT				X							X	X	X	X
3b	AEDC, VFK		X						X	X		X	X	X	X
3c	AEDC, VFK (heat transfer)								X	X	O	X	X	O	X
3d	AEDC, VFK 100" Hot-shot 1														
3e	AEDC, VKF 50" Hot-shot 2														
3f	AEDC, VFK 50" Hot-shot 1		X									X	X	X	X
4a	ASD - Wright Field Supersonic											X			
4b	ASD-Wright Field Hypersonic								X			X			
5	Astro, Marquardt Corp.	X		X								X	X	X	

X = yes, O = under some conditions

No.	Facility	IV. SYSTEM AUTOMATION													
		Self calibration during operation	Constant Determination	Matrix Inversion	Complete System Integration	Computer Control	Tunnel Start	Tunnel Stop	Model pitch/yaw	Model Roll	Surface Deflection	Data Recording	Data Reduction	Data Presentation (raw)	Data Presentation (final)
6	Ballistics Res. Lab.											X	X	X	X
7a	Boeing Transonic											X		X	
7b	Boeing Super-sonic	X			X		X	X	X	X	X	X	0 (semi corrected)	X	
7c	Boeing Hyper-sonic				0 (semi-integrated)				X			X			
7d	Boeing Hot Shot				X		X	X				X		X	
8a	Caltech JPL (old)								X	0	0	X	X	X	0
8b	Caltech JPL (new)	X	X	X	X	X			X	0	0	X	X	X	0
9	Chance Vought Corp.						X		X			X		X	
10a	Cornell Transonic	0	0	0	X	0			X	X		X	X	X	X
11	David Taylor (USN)						X	X					X		X
12	Douglas Sta. Monica	X					X	X	X	X	0	X	X	X	X

X = yes, 0 = under some conditions

No.	Facility	IV. SYSTEM AUTOMATION													
		Self calibration during operation	Constant Determination	Matrix Inversion	Complete System Integration	Computer Control	Tunnel Start	Tunnel Stop	Model pitch/yaw	Model Roll	Surface Deflection	Data Recording	Data Reduction	Data Presentation (raw)	Data Presentation (final)
13a	GD-Convair Low Speed											X	X	O Tabulations	O
13b	GD-Convair High Speed						X		X	X	O	X			
14a	Grumman Subsonic		X											X	
14b	Grumman Supersonic		X									X			
14c	Grumman Press. Inst.				X									X	
15a	Lockheed-Calif.		O	X	X			O	X	X		X	X	X	O
15b	Lockheed MSC Hot-shot														
16	Mass. Inst. of Tech.		X	X									X		X
17a	McDonnell		O				X		X			X	X		X
17b	McDonnell HIT														
18a	NAE-Canada High Speed						X	X	X	X		X		X	
18b	NAE-Canada Low Speed											X	X	X	X

X = yes, O = under some conditions

No.	Facility	IV. SYSTEM AUTOMATION													
		Self calibration during operation	Constant Determination	Matrix Inversion	Complete System Integration	Computer Control	Tunnel Start	Tunnel Stop	Model pitch/yaw	Model Roll	Surface Deflection	Data Recording	Data Reduction	Data Presentation (raw)	Data Presentation (final)
19a	NASA-Ames Unitary		O										X	X	X
19b	NASA-Ames 3.5 HWT						X	X	X			X			
20a	NASA-Langley Unitary				X							X	X	X	X
20b	NASA-Langley Central Data				X Not Incl. Computer								X		
21	NASA-Marshall						X	X	X			X	X	O	O
22	Naval Ord. Lab											X	X	X	X
23	NAA-Columbus														
24	NAA-Trisonic				X	O*	X		X			X	X	X	X
25	Northrop Norair	X	X	X			X	X	X		O	X	X	X	O
26	Ohio State Univ.		X	X					X			X	X	X	X
27	Republic		X		X		X	X				X	X	X	X
28a	Sandia Hypersonic						X	X	X			X			
28b	Sandia Trisonic						X	X	X			X			
29a	United Subsonic											X	X		
29b	United Transonic Supersonic Hypersonic		X				X	X	X		O	X		X	

X = Yes, O = Under Some Conditions * Tape Search and Read

No.	Facility	V. TEST FACILITIES DESCRIPTION Test Section Dimensions (in.)	Mach Range	Run Time	Stagn. Press. (atmos)	Remarks
1a	Aero.Res. Inst. of Sweden	40 x 40	0.5 to 2.5	20 sec	1	
		20 x 20	0.5 to 3.2	60 sec	1	
1b	Aero.Res. Inst. of Sweden	40 x 40	0.5 to 2.5	20 sec	1	
		8" dia.	4.5 to 7	Several min.	16	
2	ARL-Wright Patterson AF Base	20" dia.	8 to 14	1 min	166	T_o to 2500°R
		30" dia.	14 to 20	1 min	166	T_o to 4000°R
3a	AEDC, PWT	16ft x 16ft	0.5 to 1.6	Continuous	2	
		16ft x 16ft	1.5 to 4.0	"	2	
3b	AEDC, VKF	40 x 40	1.5 to 6	Continuous	0.2 to 13.6	
		50 dia.	8	Continuous	55	T_o = 900°F
		50 dia.	10 or 12	Continuous	13.6 to 170	T_o to 2000°F
		12 x 12	1.5 to 5	Intermittent	0.07 to 4.1	
		12 x 12	5 to 7	Intermittent	2.7 to 20.5	T_o to 1000°F
3c	AEDC, VKF (heat transfer)	50 dia.	8	Continuous	55	T_o = 900°F
		50 dia.	10 or 12	Continuous	13.6 to 170	T_o 1500°F to 2000°F
		12 x 12	5 to 7	Intermittent	2.7 to 20.5	T_o 100°F to 1000°F
3d	AEDC, VKF-100" Hotshot	100 dia.	15 to 20	40 to 70 millisecond	700 to 1400	Arc-driven -- intermittent
3e	AEDC, VKF-50" Hotshot 1	50 dia.	15 to 20	40 to 70 millisecond	700 to 1400	Arc-driven -- intermittent
3f	AEDC, VKF-50" Hotshot 2	50 dia.	15 to 20	40 to 70 millisecond	700 to 1400	Arc-driven -- intermittent

V. TEST FACILITIES DESCRIPTION

No.	Facility	Test Section Dimensions (in.)	Mach Range	Run Time	Stagn. Press. (atmos)	Remarks
4a	ASD - Wright Fld. Supersonic	2 ft x 2 ft	1.5 to 5.0	Continuous	.02 to 2	
4b	ASD - Wright Fld. Hypersonic	2 ft. dia.	8-12	2 min.	6 to 40	T_o = 4000°R
		2 ft. dia.	5-16	5 min.	3 to 120	T_o = 5000°R
5	Astro, Marquardt Corp.	14 ft. dia. 80 ft. long	to M-8	Air storage 100,000 lb	13.6	Clean air heater w/10^8 BTU/Hr vitated air heater to 4600°F. Rotating exhauster machinery 34,000 HP Cell Pressure 1.5 psia at 40 lbs/sec flow. 3 smaller wind tunnels available for models
		12 ft. x 80 ft.	to M-3.8	varies according to size	13.6	
		8 ft. x 80 ft.	to M-3.8	nozzle)	13.6	
6	Ballistic Research Lab.	13 x 15	1.5-5.0	Continuous	1/3 - 6-2/3	
		15 x 13 and 15 x 20	1.2-4.9	Continuous	1 - 4	
		14.59" dia, 15.62" dia, 18.74" dia.	6.0, 7.5 and 9.2	Continuous	150 max	Axi-symmetric, T_o to 1500°F
7a	Boeing Transonic	8' x 12'	40q to 1.15	Continuous	atmosphere (test section static varies)	
7b	Boeing Supersonic	4' x 4'	Subsonic to 4.0	30 to 46 sec.	10	
7c	Boeing Hypersonic	12 dia.	5, 6, 7 (fixed nozzles)	45 sec.	120	
7d	Boeing Hot Shot	44 dia.	12 - 22	150 ms to 250 ms	1000 max.	Max. T_o = 6000°K

		V. TEST FACILITIES DESCRIPTION				
No.	Facility	Test Section Dimensions (in.)	Mach Range	Run Time	Stagn. Press. (atmos)	Remarks
8a, b	Caltech-JPL	18 x 20	1.3 to 5.8	Continu-ous	4.4	
		21 x 21	4 to 11	Continu-ous	48	T_o to 1350°F
9	Chance Vought Corp.	4' x 4'	0.4-5.0	50 sec.	25 max.	Primary user. Tie line to Low Speed Tunnel for pressure recording.
		13.5	14 -21	50 milli-second	2,000 max.	Playback and read mag. analog tape. Can also read telemeter tape.
10a	Cornell Transonic	8' x 8'	0 to 1.3	Continu-ous	1/6 to 2 1/2	
		Mn 6 - 6 x 6 Mn 15 9.5 dia.	6.0 and 15.0	15 sec.	to 195 atmos.	Use Computer <u>only</u>.
		24 dia. and 48 dia.	6.0 to 29.0	3 milli-seconds-10 milli-seconds	270 atmos. nozzle supply press.	Use Computer <u>only</u>.
10b	Cornell W. S. Hyper-sonic	9' nozzle exit	15	15 sec. max.	200	Max. T_o = 9000°R
		8 x 8	6	15 sec. max.	200	Max. T_o = 9000°R
11	David Taylor (USN)	9 1/2 x 9 1/2	Sub to 4.5	148 sec.	1	
		12 x 12	Sub to 4.0	90 sec.	1	
		18 x 18	Sub to 4.5	27 sec.	1	
		13 1/2 dia.	M = 5, 7, 9, 10	100 sec.	40 atmos.	Open jet.
12	Douglas Santa Monica	1' x 1'	0.2-3.5	60 sec +	6.5	
		4' x 4'	0.2-5.0	30 - 60 sec.	20	T_o to 200°F
		2' dia.	6, 8 and 10	90 sec.	150	T_o to 2000°F

No.	Facility	V. TEST FACILITIES DESCRIPTION Test Section Dimensions (in.)	Mach Range	Run Time	Stagn. Press. (atmos)	Remarks
13a	GD-Convair Low Speed	8' x 12'	to .35	Continuous	Atmospheric test section	
13b	GD-Convair High Speed	48 x 48	0.5 to 5.0	35 - 90 sec.	1.5 - 22	Blowdown
14a	Grumann Subsonic	7' x 10'	0 - .2	Continuous	1.0	
14b, c	Grumann Supersonic	1' x 1'	1.4 to 4.0	60 sec.	3 to 20	
15a	Lockheed Calif.	4' x 4'	0 - 5.0	Avg. 45 sec.	25	
		8' x 12'	0 - 0.3	Continuous	1	
15b	Lockheed MSC	28" dia.	15-25	35 mill. sec.	1000	
16	Mass.Inst Tech.	18 x 24	1.5 to 4.0 and 7.6	Continuous	0 to 3 atmos.	
17a	McDonnell PSWT	4' x 4'	0.5 to 5.8	30 sec. (Avg.)	27.2 (Max.)	
17b	McDonnell HIT	30" dia. & 50" dia.	8.0 to 29.0	40 ms to 100 ms	1.0 to 2500	Max. stag. temperature = 6500°K
18a	NAE-Canada High Speed	5' x 5'	0.2 - 4.5	10-20 sec. min.	20 atm	
18b	NAE-Canada Low Speed	6.3' x 9'	0 - 0.3	Continuous	1	

V. TEST FACILITIES DESCRIPTION

No.	Facility	Test Section Dimensions (in.)	Mach Range	Run Time	Stagn. Press. (atmos)	Remarks
19a	NASA - Ames Unitary	8' x 7'	2.5 - 3.5	Continuous	.4 - 2.0	These 4 facilities utilize identical data acquisition systems. Data from these facilities are reduced on a single computer (H-800) at a remote data reduction center.
		9' x 7'	1.5 - 2.5	Continuous	.4 - 2.0	
		11' x 11'	.7 - 1.4	Continuous	.5 - 2.4	
		14' x 14'	.5 - 1.2	Continuous	1.0	
19b	NASA-Ames 3.5 HWT	3.5' dia.	5 - 15	1-4 min.	3-120	T_o up to 2100°R later to 3600°R
		14 dia.	10 - 22	1-5 min.	to 150	
20a	NASA-Langley Unitary	48 x 48	1.5 - 2.9	Continuous	4.0	T_o = 610°T
		48 x 48	2.3 - 4.6	Continuous	10.0	T_o = 610 - 740°R
20b	NASA-Langley Central Data	31 x 31 (hyp.)	9.5 - 10.2	Continuous	15 - 150	T_o = 1560 - 1960°R
		31 Hyp.	11.5 - 12.1	Continuous	30 - 300	T_o = 2080 - 2820°R
		72 x 105 (Therm. Struct.)	3	15 - 75 sec.	3.3 - 13.6	T_o = 760 - 1120°R
		96D (Hi. Temp. Struct.)	7.0	30 - 240 sec.	27 - 270	T_o = 2500 - 4500°R
		186 x 186 (Transonic)	0.2 - 1.1	Continuous	1.0	T_o = 500 - 640°R
		85 x 85 (Trans. Press.)	0.6 - 1.43	Continuous	.25 - 1.0	T_o = 583°R
		54 x 54 (Sup. Press)	1.4 - 2.0	Continuous	.25 - 2.0	T_o = 570°R
		20 x 20.5	6	1/2 hour	20 - 37	T_o = 860 - 1010°R
		20 x 20.5	3	1/2 hour	3.4 - 37	T_o = 530 - 1010°R

No.	Facility	V. TEST FACILITIES DESCRIPTION Test Section Dimensions (in.)	Mach Range	Run Time	Stagn. Press. (atmos)	Remarks
20b	NASA-Langley Central Data (cont'd)	22D	8.5	1/2 hour	122 - 200	T_o = 1510°R
		12 x 14	6.0	120 sec.	1.35 - 48.0	T_o = 860 - 1060°R
		18.5 D	8.0	60 - 90 sec.	3.4 - 68	T_o = 1260 - 1560°R
				Continuous	150 - 200	T_o = 1260 - 1560°R
21	NASA-Marshall	7 x 7	1.5 - 4.3	1 - 4 min.	1	
		14 x 14	0.5 - 5	1/2 - 3 min.	7	
22	Naval Ord. Lab.	20 x 20	5 - 10	1 1/2 min. to Continuous	15 to 150	T_o to 1500°F
23	NAA-Columbus	7' x 10'	0 to .349	Continuous	1 at V = 0	
		14' x 16'	0 to .09	Continuous	1 at V = 0	
24	NAA-Trisonic	7' x 7'	.2 to 3.5	5 to 30 sec.	1 to 8	Tunnel is of the intermittent blow down type
25	Northrop Norair	7' x 10'	0 to 0.4	Continuous	Atmospheric	
		2' x 2'	1.5 to 5.0	45 sec.	20.0	Blowdown
		30" dia.	6.0 to 14.0	40 to 300 sec.	200	T_o to 3200°R - Blowdown
26	Ohio State University	12 x 12	Transonic	40 sec.	5	
		12 x 12	Supersonic	40 sec.	100	
		12 inch	Hypersonic	Continuous	100	
27	Republic	20 Octagonal	.60 - 1.30	38 sec. max.	5	

V. TEST FACILITIES DESCRIPTION

No.	Facility	Test Section Dimensions (in.)	Mach Range	Run Time	Stagn. Press. (atmos)	Remarks
27	Republic (cont.)	15 x 15	1.50 - 4.00	150 sec. max.	33	
		36 dia.	8, 10, 14	30 - 60 sec.	200	
28	Sandia Hyper-sonic	18 D	5 and 7.5	45 sec.	19 max.	
		5 D	4 and 9	2 min.	19 max.	
28b	Sandia Trisonic	12 x 12	0.4 to 3.0	1 min.	5 max.	
29a	United Subsonic	18-feet Octagonal	0 - .25	Continu-ous	Atmos-pheric	
		8-feet Octagonal	0 - .95	Continu-ous	Atmos-pheric	
29b	United Transonic	17 x 17 transonic	.5 to 1.5	60 sec. max.	5	
		17 x 17 supersonic	1.5 to 5.0 flex plate	90 sec. max.	25	
		6 x 6 Hypersonic	4.3 to 9.5	90 sec. max. for blowdown. Continu-ous in the range 4.3 to 8.0	60 blow-down 25 con-tinuous	T_o to 1800 R (pebble bed)

VI. EXPLANATIONS AND COMMENTS

No.	Facility	
1b	Aero Inst. of Sweden	The system is movable. The system is also used in connection with heat-transfer tests in the Structures Dept.
2	ARL-Wright Patterson AFB	Practical system accuracy in 4 digit mode is 0.05%, and in 3 digit mode 0.2%. Solid state commutator at high levels allows maximum programming flexibility.
3a	AEDC PWT	Brief descriptions of the subsystems comprising the overall digital data processing systems are outlined below:

1. Force or Strain Gage System (Force Balance Readout)

   Each channel consists of a Beckman Fitgo pre-amplifier, gage power supply, bridge balance unit, Dymec voltage to frequency converter, and gated counter. Full scale ranges of 0 $\pm$ 5, 0 $\pm$ 10, 0 $\pm$ 20, 0 $\pm$ 40 millivolts are available. Full scale count $\pm$ 10,000 counts. BCD digital output is available for entry into the computer raw data system. Gating periods of 1-2-4-8 or 16 seconds are available for obtaining average values of gage outputs.

2. Temperature System

   Conventional Beckman 210 high speed data acquisition system. Digital output can be entered directly into the computer at the rate of 20 channels per second or recorded on magnetic tape at the rate of 3,000 channels per second. Magnetic tape data is usually processed on a centrally-located IBM 7070 computer. A magnetic-tape-to-paper tape converter is available if ERA 1102 processing is required.

3. Pressure

   This system is comprised of 50 CEC 1-126 high speed

No.	Facility	
3a	AEDC PWT (Cont'd.)	servo amplifiers and 250 CEC Type 4-332 pressure transducers. Five transducers are commutated into each servo amp. Transducer ranges of ± 1.5, ± 5, ± 15, ± 60 and ± 500 psid are available. System is capable of providing full scale count for 1/2, 1/4, 1/8, and 1/16 of nominal full scale transducer range. Analog data are digitized by the use of Dymec voltage-to-frequency converters and gated counters. Full scale output count is ± 4000 counts in natural binary code.

All systems, including tunnel condition readout, are actuated and controlled by a Master Print Control System. Digital outputs of all systems are digitally commutated into the computer raw data system at the rate of 20 channels per second. Data reduction may be fully automatic and on line if desired. Most common operation is a modified on line mode in which paper tape generated by computer raw data section is hand fed into the computer main frame tape reader. This mode allows faster tunnel operation with only a slight delay in the generation of final data.

A similar data acquisition system has been in use in the PWT 16-ft. Transonic Tunnel since 1957. The force or strain gage system (10 channels) is identical to that used in the 16-ft. Supersonic Tunnel. The high speed temperature system (Beckman 210) used in the supersonic circuit is shared by the transonic tunnel. The 16-ft. transonic digital pressure system is comprised of 50 each CEC 1-124 MA servo amplifiers and up to 250 CEC 4-330 pressure transducers. Five transducers are time shared on each servo amplifier. Digital outputs from shaft position digitizers (Coleman P-15-D) are read into a computer at the rate of 20 channels per second.

The ERA 1102 computer described in Section II, COMPUTER SYSTEM, is shared by the Transonic and Supersonic tunnels.

No.	Facility	
3b	AEDC VKF	The ERA 1102 contains two Raw Data Sections. By means of cross-bar switches, each of these data acquisition units may be connected to any one of five relay scanners located at the tunnel sites. Each relay scanner has the capacity to scan 84 binary readouts.

Five high-speed paper tape punches are switched in conjunction with the relay scanners. Therefore, each tunnel has a unique output device, regardless of which RDS unit is utilized. This enables data acquisition from any two tunnels at the same time. These raw data tapes are read into the computer for reduction of final data on an off-line basis.

The computer is equipped with four identical storage drums. This multiple-storage capability allows the computer to operate sequentially on more than one data reduction program without the necessity of reading a new program into the memory at each change-over.

Signal conversion is accomplished primarily with DC and AC servopotentiometers. These instruments are equipped with angular position encoders to provide binary readouts to to the scanners.

Several instrument systems are employed at each tunnel location. A typical tunnel instrument complement consists of the following equipment:

Pressure: 9 channels equipped with pressure scanning valves for a total capacity of 99 model ports. Variable reluctance transducers with frequency-modulated outputs are used. Gated frequency counters provide binary readouts.

Force: AEDC-designed 400 cps precision servo-indicators are employed to measure strain gage outputs. Encoders provide binary readouts. The basic system consists of eight channels, but this is expandable to sixteen as required.

VI. Explanations and Comments (Con'd)

No.	Facility	
3b	AEDC VKF (Cont'd.)	Temperature: Five DC servopotentiometers are used for static thermocouple measurements. Attached encoders provide binary readouts to the scanner. 100 channels are available for dynamic temperature measurements by the Beckman 210 system. Model Attitude: Shaft position encoders driven by the model positioning servo systems furnish binary readings of pitch and roll.
3c	AEDC VKF (heat transfer)	This acquisition system is used primarily for heat transfer data. The Beckman 210 is a very reliable system. The FITGO amplifiers are chopper-stabilized and employ input filters. These amplifiers are exceptionally stable over long periods of time.
3f	AEDC VKF - 50" Hotshot - 2	Data are initially recorded in a magnetic core storage unit. After the tunnel run is completed, the data are transferred from the core to punched paper tape. The core capacity is 1092 words. Work is presently under way to increase the number of channels to 50, the scan rate to 17 kc, the word size to 12 bits binary, and the core storage capacity to 4,000 words. Either the ERA 1102 computer or the IBM 7070 computer can be used for final data reduction.
4a	ASD - Wright Fld. Supersonic	98-Channel strain gage recording system also available which records on IBM 523 Summary Punch. Use is dictated by availability of appropriate strain gage pressure transducers to meet specific test requirements. General-purpose 98 channel transducer-pneumatic system in fabrication and 80% complete.

No.	Facility	
5	Astro, Marquardt Corp.	Primary aim of system was to reduce data reduction time while maintaining high accuracy and quality of data. System has been used for several hundred test programs for the past 7 years. System is in operation about 40 hours per week.
6	Ballistics Research Lab.	High system accuracy and flexibility with moderate speed of raw data acquisition. On-line reduced data has not been considered due to ready availability of high performance computers within the BRL. Raw data acquisition system has been in use servicing SSWT-1 and SSWT-3 for 7 years for an average of approximately 20 hours per week. SSWT-4 has been brought into the system during this year and utilizes the complete arrangement of data acquisition except that 7 individual channel Electro-Instruments Model 400 X-Y plotters are used in place of the Hanson-Gorrill-Brian 6-channel plotters used in SSWT-1 and SSWT-3. A separate data acquisition system designed expressly for SSWT-4 by Dynametrics is partially installed at this date. When completed, SSWT-4 will be dropped off the older Hanson-Gorrill-Brian raw data acquisition system.
7a	Boeing Transonic	1. Force Balance Calibration
7b	Boeing Supersonic	The recording and processing of force balance calibration data is now automated. The loading of the weights remains a manual procedure, but is performed according to a rigorous loading schedule.
7c	Boeing Hypersonic	These calibrations are automated by using a special six-channel data recording system. It is specifically designed for this purpose and is so successful that there is no manual handling of the data from the time it is generated until the constants have been computed and
7d	Boeing Hot Shot	

No.	Facility	
7	Boeing (Cont'd.)	returned from the Boeing IBM 7090 in a standardized listing. The weight loading program has 330 coded conditions which produce 330 punched cards each with the 6 outputs from the balance. Processing on the IBM 7090 uses 32K core positions and consumes 1 1/2 minutes of machine time. The output from this program is an IBM listing of 20 pages of data. Three pages are required for the constants from each component of the balance. Two additional pages are for summary. The constants evaluated by the program are the first order, second order, and cross-product terms, a total of 27 terms for each component. Many balances exhibit some zero or negligible interaction terms, but nevertheless all terms are evaluated by this program.

2. <u>Wind Tunnel Data Processing Steps</u>

All of the raw wind tunnel data is ultimately put in punched card form. In the Transonic, Supersonic, and Hypersonic (force and pressure data) this is achieved by the strip chart recorder systems directly, using standard or modified (Supersonic Tunnel) IBM equipment. In the Hypersonic and Hotshot, extensive use of oscillographs for heat transfer and other multi-channel tests requires a productive means of encoding the data from the graphs into IBM cards. This requirement is satisfied by a Benson-Lehner Oscar oscillograph reader.

Once the data are in cards, they are corrected to eliminate errors, merged with the program deck, and submitted to a satellite station for the 7090. This satellite station is an IBM 1401 whose function is to transfer the data contained on cards to magnetic tape. Greater utilization of the 7090 results from using

No.	Facility	
7	Boeing (Cont'd.)	magnetic tape as its input. Processing then occurs on the 7090. After the answer tape is generated by the 7090, the tape is submitted to the 1401 for high speed listing of the data. The final data listings are given to a group of girls whose job is to plot the data in report quality format. The wind tunnels are utilizing 1.63% of the 7090's available time or 17.11 hours. In addition, 58.60 hours are being spent on electronic accounting machines such as collators, punches, and tabulators. The total bill is about $6,072/month. These typical figures are for the month of June, 1962. 3. Pressure Data Pressure data is obtained in the Transonic, Supersonic, and Hypersonic by commutating with commercial Scanivalves. They are very suitable for Boeing's particular application. Scanivalve Company is now producing a modification of a Boeing valve design in which the valve bodies can be added up to about ten per drive unit. Their application is very flexible and the configuration can obviously be optimized to suit the interior of the model.
8a	Caltech - JPL (old)	High system accuracy attained by utilizing an all-digital system with individual amplifiers and digitizers on each channel and commutation by stepping switches at high signal level. System has been used for several hundred test programs covering millions of component-data-points over the past 5 years. System is in operation about 40 hours per week. Superseded by new integrated high speed system in mid-1963.

VI. Explanations and Comments (Con'd)

No.	Facility	
8b	Caltech - JPL (new)	System described in Section V-B of this report.
9	Chance Vought Corp.	Can read 384 channels of pressure data for internal Scanivalve system in 2 seconds. Careful attention to shielding low-level signals and noise cancellation by running twisted-quaded pairs plus single point ground resulted in very low noise levels. The gain may be varied to yield ± 1000 counts for ± 1 millivolt, thus getting maximum accuracy for 3 digit data. This system was a sort or "prototype" for the Beckman 210 system, which appears to be an excellent system for wind tunnels. With about 2,000 vacuum tubes, the CV system has about 12 KW of heat to dissipate. Later systems using more transistors are much better. Time-sharing the system is awkward due to changes required in filters, gain-setting, etc.
10a	Cornell Transonic	The acquisition equipment covered is used for the 8-foot transonic tunnel only. All the computing equipment is available to the three facilities. Acquisition equipment is in use approximately 80 hours per week. The computer system, used jointly, is in operation for an average of 100 hours per week. All equipment covered has been in continuous service for several years and found to be very accurate and dependable. Shock tunnel data acquisition system CEC 502 oscilloscopes and Beatty land cameras. 32 channels. Low-level pre-amplifiers CAL design. Variable notch filters and low pass filters (600-1500 cps) CAL design.

VI. Explanations and Comments (Con'd)

No.	Facility	
10b	Cornell W.S. Hypersonic	New facility, initial contracts testing starting November, 1962. Facility can also be used without tunnel systems for High Heat Flux Testing of materials. Presently using CEC 123 and 124 direct writing oscillographic system for data acquisition. Development of digital system in work which will eventually tie-in with the computing and presentation systems described for the CAL Transonic Tunnel.
12	Douglas Santa Monica	16 channel system can be used as a 32 or 48 channel system by using one or two tunnel setup consoles. Readout time per data point then becomes 1.6 or 2.4 seconds. 160 pressures can be read out by data system in 8 seconds using pressure scanner.
13b	GD-Convair High Speed	Due to low absolute pressures encountered at high Mach numbers, with the consequent pneumatic response problems, the system employs individual, local, pressure transducers for each orifice to be monitored. Up to 125 such channels may be read in 1.2 seconds. Fewer channels - in multiples of 25 - may be read in proportionately less time. The use of individual transducers permits flexible (individual) filtering if required. Elapsed time between readings of adjacent channels, within a group of 25, is 2.5 milliseconds. By the use of scheduled preventive maintenance, excellent reliability has been obtained. The system is in use approximately 80 hours per week with power maintained continuously on temperature sensitive components.
14a	Grumman Subsonic	System designed for immediate access to high accuracy raw data with provisions through punched paper tape for automatic data reduction at main plant. The above system,

No.	Facility	
14a	Grumman Subsonic (Cont'd.)	for strain gage outputs, augments the wind tunnel mechanical balance which gives six-component force data output on IBM punched cards. Data output from the mechanical balance is processed by the central computing center on IBM 7090 equipment, and final corrected data are plotted on Electronic Associates Model 3033-1A-2 data plotter.
14b	Grumman Supersonic	Oscillograph recording system using GAEC strain gage balance unit and Pace Thermocouple Control units. Telephone switchboard type interchangeability for putting data inputs on galvos. Automatic data reduction of oscillograms available at main plant.
14c	Grumman Pressure System	Special system for recording many pressures rapidly with high accuracy. Data presentation in digital form on Flexowriters as well as 5-hole punched paper tape for data reduction at main plant.
15	Lockheed California	Future plans include the following modifications to enable utilization of the data processing system for additional facilities (hypersonic wind tunnel, propulsion tunnel, and test cells). 1. Increase number of low-level amplifiers and high-speed commutators to 40. 2. Provide a remote control console and display for the data gathering system. 3. Add tape search capability to recording equipment. 4. Add separate calibration data gathering system. 5. Provide "gapless tape" recording capability. 6. Add 8000 character core storage to computer.

No.	Facility	
15	Lockheed California (Cont'd.)	7. Provisions for simultaneous utilization of the data gathering equipment by two different test facilities, dividing the 40 amplifiers between them as needed. 8. Provisions for time sharing of the data gathering equipment by up to seven separate test facilities, twenty low-level channels to each, selection by low-level stepping switches.
16	Mass. Inst. Technology	This system has been used extensively over the past 5 years. It is still in use during 8-10 test programs each year. At the present time there are no plans to replace this with a more up-to-date installation.
17a	McDonnell PSWT	1. The Hotshot tunnel uses oscillograph and manual data reduction methods. Future plans for the Hotshot tunnel contemplate magnetic tape recording of Hotshot data with low-speed playback capabilities so that the system for the Polysonic tunnel may be used for digitizing and the subsequent data processing procedures. The additional Hotshot equipment required has not yet been purchased. 2. The Microsadic is an all transistorized system. Greater reliability than similar systems using vacuum tubes is attained. System is in use about 80 hours per week.
17b	McDonnell HIT	Effective August 1963, McDonnell's Hypervelocity Impulse Tunnel will record data on a 60-channel high speed FM loop tape recorder. The tape will be played back at reduced speed, digitized, transmitted over land lines to the company's IBM 7090 computer for processing. Final data will be transmitted by wire back to local Engineering Laboratory Data

No.	Facility	
17b	McDonnell HIT (Cont'd.)	Center where it will be tabulated and plotted in final form - approximately 45 minutes after tunnel is fired. The HIT analog data will be digitized on the Microsadic unit in the PSWT or alternatively, at a new (April, 1963) Central Data Station for the McDonnell Engineering Laboratories.
18a	NAE-Canada High Speed	This system consists of 10 digitized 0.25-second Brown recorders Azar type with 10 K input impedance. Full-scale ranges of 2, 5, 10, and 20 mv. are available. The digital output from the self-balancing potentiometers is recorded in parallel by an IBM 523 punch. Model attitude is also digitized and recorded on the punched cards.
18b	NAE-Canada Low Speed	This system has 27 input channels, six of which are occupied by the force balance components, two by the model position in pitch and yaw, and one each by the dynamic pressure, temperature and model propeller motor r.p.m. The remaining 17 are used for digitized self-balancing potentiometer readings. The punched tape output is converted to punched cards by an IBM 047, and the cards are manually transferred to the 1620 computer. An automatic programmable model attitude drive system is being designed. A data system similar in concept to the 18a has been designed for the 15 foot vertical wind tunnel. This data system will utilize the IBM 1620 computer.

No.	Facility	
19b	NASA - Ames 3.5 HWT	Data tape recorded in IBM 704 or 7090 format. Amplifier gains: 1, 4, 10, 40, 400 mv input for f.s. (5v) output. Amplifier outputs (+10 hi level channels) commutated (solid state) to single (Packard Bell) ADC. Max. system accuracy approximately $\pm$ 1 μ v. Another identical system (except 50 amplifiers installed) is used by the Ames 12" Hypersonic Helium Tunnel.
20a	NASA-Langley Unitary	1. At present, there is one real-time data processing system in use at the Langley Research Center. It is used in conjunction with the static testing of force models in the two test sections of the Unitary Plan wind tunnels. With this system, strain gage balance and other related transducer outputs are converted to decimal numbers using shaft encoders operated by null-balance servos. The outputs of these converters are scanned sequentially, converted to binary coded decimal form and transmitted (serial by character) over telephone lines to the Data Reduction Center. A punched paper tape is used at the Data Reduction Center to record the incoming data and to serve as a buffer between the tunnel readout equipment and an IBM 1620 computer. Data for each test condition are read into the computer, converted to final coefficients, scaled and transmitted back to the test facility for presentation on a flexowriter and 11" x 17" plotters. The system has been operating since June, 1962 with the use rate being governed by the force tests run at the Unitary tunnels. 2. A number of the Langley Wind Tunnels use punched card readout equipment to record strain gage and pressure

No.	Facility		
20a	NASA - Langley Unitary (Cont'd.)		data from static tests. In these cases, the decimal outputs from the servo-driven shaft encoders are fed to tabulators and summary punches located at the wind tunnel. The cards are hand carried to the Data Reduction Center for processing in the IBM 7070 computer. Processed results can be plotted using general purpose card and tape input plotting equipment. Assuming the computer programming is completed prior to the start of the testing, results can be available within an hour following the completion of a run.
20b	NASA - Langley Central Data	1.	Thirteen test sites have been integrated into a Central Data Recording System, and work is underway to connect six additional sites. Three Beckman 210 Digital Recorders are located in the Data Reduction Center and are used to record data from all the test sites connected into the system.
		2.	One of these recorders can handle 220 analog channels and 20 digital channels. The other two recorders are each capable of recording 100 analog and 20 digital channels. A multi-range low-level amplifier is used for each analog channel to provide a full scale output of $\pm$ 5 volts for full scale inputs ranging from $\pm$ 6.25 millivolts to $\pm$ 100 millivolts. A programmable electronic scanner switches the amplifier output voltages to an analog-to-digital converter at the rate of 2400 measurements per second. The output of the converter and the twenty digital channels are recorded on magnetic tape in a format for the IBM 7070 computer at the rate of twenty 120 channel frames per second. Recording is accomplished at this speed in a continuous mode, or a single frame can

No.	Facility	
20b	NASA - Langley Central Data (Cont'd.)	be recorded in 1/20 second under push button or other programmed control.
		3. One novel operating feature of the recorders permits a single frame recording of the amplifier attenuator settings in the same tape format as the data. Although the attenuators are set manually according to the requirements of the data to be recorded, the automatic recording of these settings eliminates the human logging error and makes these constants available to the computer in the input tape containing the data.
		4. Tapes containing the recorded data are carried to the machine room for processing on the IBM 7070 computer. General purpose programs have been developed to convert the input tapes to physical quantities (temperatures, pressures, strains, displacements, etc.) so that the normal elapsed time is about 24 hours. Since the processing time is 20 minutes per reel of tape, this time can be reduced to an hour when required.
		5. Double shielded, multiple twisted pair telephone cables are used to carry the millivolt level signals from the test site transducers to the recorders. The maximum cable length now used is one-half mile. A patchboard switching network in the Central Recording room allows data from any of the test sites to be recorded on any one of the three recorders.
		6. A direct wire telephone communication system allows the engineer at the test site to request recording service and to call in the desired amplifier range settings. The test site-recorder connection, range setting, and

No.	Facility	
20b	NASA - Langley Central Data (Cont'd.)	recorder pre-run checkout can be accomplished on fifteen minutes notice. After the system is set up, control is passed to the operator at the test site who initiates the starting and stopping of the recording. 7. The number of test measurements recorded varies with the operating schedule of the test sites. At present it averages about one and one-half million measurements per month. 8. System calibrated in absolute millivolts against a secondary standard giving counts/mv. Calibration checked daily. Amplifiers have selectable full scale ranges: zero to 6.25, 12.5, 25, 50, or 100 mv.
21	NASA - Marshall	Other facilities utilize the computer and associated data reduction equipment. A hypersonic shock tunnel under construction has not been included.
22	Naval Ord. Lab.	Raw data recorded for off-line reduction on IBM 7090. Analog computer (NOL design) used on-line for computation of force and moment coefficients and recording on Moseley XY plotters. On-line display of raw data by bargraph CRO. Raw data tape can be read and displayed (off-line) on Electronic Associates plotting system as check prior to IBM computation.
23	NAA - Columbus	The digital recording system utilizes stepping switches to switch input amplifiers in banks of 20 inputs. Each bank of 20 input channels is then commutated by a high-speed electronic scanner at a high signal level. A high-speed electronic analog-to-digital converter then translates the commutated high level analog signals present on any selected

No.	Facility	
23	NAA - Columbus (Cont'd.)	channel to an equivalent digital value. The digital number for each channel is stored in a magnetic core storage unit until all channels selected have been digitized. When this information has been completely stored, the memory is read and transferred to magnetic tape in a format directly compatible with the IBM 709 computer.
24	NAA - Tri-Sonic	Data flow from acquisition to presentation during normal tunnel operation is as follows: Model and tunnel operating parameters are continuously sampled and recorded on magnetic tape in binary digital form during tunnel blow down. On completion of tunnel blow, the recorded tape is mounted on the computer play-back tape deck for computer programmed tape search, read, reduction, and card punch of raw data in decimal form, and computed coefficients for tabulating on an IBM 407 tabulator and punching of plot cards for plotting on a digital plotter. The sector is capable of rotation through a pre-determined angle of attack range and at controlled pitch rates from nominally 0 to 5°/sec. In addition, a pitch and pause mode of automatic sector positioning is available consisting of ten pre-selected angles for pausing with a pause time varying from .5 to 5 seconds.
25	Northrop Norair	The data system is in vendor/procurement stage at this time. Approach is to obtain an expandable design, permitting recording from any one of three test areas. On-line computer will be added late 1963. Maximum scan rates up to 15 KC per data channel are realized. No change over from one test area to another is required. System will continuously scan data from all three wind tunnels. Recording on demand of local controls. System uses individual tape units for each tunnel.

No.	Facility	
27	Republic	The wind tunnel data acquisition system sequentially samples the output of 100 low-level transducers located in any one of the three wind tunnels, converts these samples to digital code, and records this data on magnetic tape for use with the IBM 7090 computer.
28 a, b	Sandia	The wind tunnel data is reduced by Sandia's data reduction group. They have a great deal of associated equipment such as plotters, telereaders, analog computers, etc. The tunnel data reduction is a very small percentage of their work load. All equipment mentioned is used in wind tunnel data reduction.
29a	United Subsonic	This system was custom designed and built specifically for the purpose of recording data from a helicopter rotor test rig. Multi-bladed rotors 9 feet in diameter are tested at rotational speeds up to 1800 rpm in the 18-ft. test section. Recorded data include the output of the 6 strain gage load cells of the 6-component balance, blade strain gages, rig rpm, and 3 outputs of blade motions from rotary transducers. The system also records tunnel test conditions automatically, and records 23 digits of manual parameter board input. It is capable of recording from 9,000 to 15,000 pieces of data per second on 1-inch magnetic tape, depending on the number of channels being sampled. The data are transmitted over coaxial cables to an off-line IBM 727 tape unit located 600 feet away in the UAC computing laboratory. This tape becomes the input to either of two IBM 7090 computers which are available for use by all divisions of UAC. The system required a great deal of shakedown and debugging--an effort which extended over a period of about one

No.	Facility	
29a	United Subsonic (Cont'd.)	year. It is presently operating in the range of 90 to 95% up-time.
29b	United Transonic	Analog-to-digital conversion is via mechanical shaft position encoder. Computer will produce cards with reduced data. Reduced data plotted automatically on Moseley XY plotter.

V. CURRENT SYSTEMS (Con'd)

B. New JPL System

1. System Organization

a. General

A computer-controlled data processing system has been developed by ASTRODATA, Inc. (Reference 38) to control automatically the priority, the selection and sequencing of data from the wind tunnels at the Jet Propulsion Laboratory. This section briefly describes the organization and design of the system. The decision was made to utilize a time-shared system with a general-purpose digital computer used to set up the priority of data servicing. The computer also sets up the data channels to be acquired and the system's sampling rate. In addition, the digital computer is capable of averaging selected channels or doing other data correlation calculations on-line. The system at present is designed to receive data from three test areas. At the test areas, the signals are received, conditioned and transmitted in analog form to a central location. At the central location, the low-level analog signals from the test sites are brought to an analog-input patchboard. From this patchboard, the desired signals are slected, amplified, digitized, placed into proper format under computer control and recorded on magnetic tape. Figure V-4 shows the basic system arrangement.

b. Data Acquisition Sub-System

A Data Acquisition Sub-System is provided at each test area. The test area sub-systems in turn communicate, through the Central Data Unit, with the system's on-line digital computer. More test area sub-systems can be readily added at future testing sites, or the number of channels can be increased at an existing site. Included in the sub-systems at each test area are:

thermocouple reference junction boxes
strain gage termination boxes
strain gage conditioning modules
strain gage monitor display panel
data word display unit
computer output punch

The test area sub-systems are basically identical in design and construction. Figure V-5 shows a block diagram of a test area sub-system.

c. Central Data Unit

The central data unit of the automatic integrated data system receives, at its input patchboard, low-level analog signals from the test area sub-systems. By means of the patchboard, channels are selected to be multiplexed and/or amplified, converted to digital form and routed to the on-line digital computer. Included in the central data unit are:

input patchboard
calibration sub-system (voltage substitution)
low-level multiplexer
differential amplifiers
high-level multiplexer
analog-to-digital converter
digital display unit control
digital data registers
time-word generator
acquisition control
computer interface

Figure V-6 shows the routing of input signals through the central data unit.

d. System Control

Control panels are provided at each wind tunnel, at the set-up area, and at the central data unit. Figure V-7 shows the wind tunnel control panel. The control panels at the other locations are similar. The operator gains the attention of the computer by setting up his request number and momentarily pressing the "request execute" button. The computer then assigns a priority to the request. The "awaiting service" indicator for the requesting area is then lit. The "request" display indicates the priority sequence for the various sites. The requesting operator then sets up the initial point number for his test. This number is automatically up-dated one count for each scan of his data. The operator also sets up the identification code and run number for the test. This digital data is recorded at the start of the data frame. From the control panel the operator can select any channel for digital display. This feature facilitates the set-up and check-out of the instrumentation for a test. When the computer is servicing a particular site only the data from that site can be selected for display. At the central data unit, alarm limits can be set up for twelve specific inputs. When an alarm limit is reached, its alarm indicator lamp is illuminated on each control panel. If the alarm is not of interest at a particular site, the alarm indication can be inhibited. The control features of the system permit the following modes of operation:

1) Interlocks to prevent interference between test areas within the complex.
2) Programmable priority of recording requests.
3) Controlled sequencing and programming of channels.
4) Ability to make a pre-run and post-run calibration check on the transducers and the system, using calibration resistors or reference voltages.
5) Continuous recording of any or all channels, on magnetic tape, at high speed.
6) A single channel displayed at test area while the system scans, independent of recording.
7) Periodic single-scan recording of any or all channels, at high speed.
8) Averaging of selected channels.
9) Transmission of selected data to computer output punches in test area.
10) Monitor-alarm 12 selectable strain-gage channels at each wind tunnel.

2. Major Components

a. Thermocouple Reference Junction Boxes

The system has the capabilities of measuring as many as 150 temperature signals from thermocouples from each of the wind tunnel sites and 50 temperature signals from thermocouples at the set-up location. Constant-temperature reference junction boxes are used. The boxes maintain a temperature of 150°F $\pm$ 1/10°F over an ambient temperature range of from -30°F to $\pm$120°F. Temperature variations between junctions in the box are held to within $\pm$1/10°F. Each thermocouple reference-junction box accommodates 50 thermocouples. Each reference-junction box handles the following types of thermocouples:

1) iron-constantan
2) copper-constantan
3) chromel-constantan
4) chromel-alumel

A special shielded, thermocouple reference-junction box is used to minimize leakage resistance and capacitance between reference junctions and between junctions and ground at the reference box. This leakage, if present, causes common-mode-voltage errors. Figure V-8 shows how the common-mode signals produce a differential error signal <u>if the guarded reference-junction box is not used</u>. In conventional reference-junction boxes, the leakage resistance to ground is approximately 500 megohms and the unguarded capacitance is normally in excess of 100 picofarad (26×10^6 ohms at 60 cps). The following example shows a compilation of errors using an unguarded reference-junction box.

1) Assume a copper-constantan thermocouple with #18 leadwire located 100 feet from the reference-junction box.

100'	copper	=	.58 ohms
100'	constantan	=	16.53 ohms
	difference		15.95 ohms/100 feet

2) Further let us assume a common-mode voltage of 10 volts (rms) at 60 cycle.

$$\text{Error} = \frac{10\sqrt{2}}{26 \times 10^6 + 16} \times 16 = 8.7\mu V$$

Increasing the leadwire run will proportionally increase the error.

b. Signal Conditioning Modules

The test area sub-systems supply the necessary signal conditioning equipment to excite bridge-type transducers, adjust their excitation voltage, balance any residual signal from the transducer and permit the calibration of these transducers. In this system, a removable, plug-in, "universal" etched circuit card is provided for each transducer. On this board are mounted the necessary balance, span and calibration resistors and potentiometers for the transducer. Figure V-9 shows the configuration of a "universal" conditioning card. By the addition or deletion of bridge-completion resistors, the cards can be converted to accommodate any of the following inputs: potentiometers; one arm-bridges, or resistive temperature devices; two arm-bridges; four arm-bridges, current or voltage sources. A monitoring jack is provided on each signal conditioning card to facilitate calibration. Calibration relays are provided on each conditioning card. A switch on each card enables the calibration to place a +80% or a -80% shunt across an arm of the transducer. The excitation voltage is then adjusted so that the output of the transducer is +80% (or -80%) of full scale. Under system control, the relays are simultaneously operated to enter and record calibration data in the automatic calibration mode of operation.

c. Input Patchboard

A patchboard is provided at the input to the central data unit. High-quality analog signal cables inter-connect the test area sub-systems to this central data unit patchboard. The patchboard functions as a "switch", enabling the test operator to select the inputs that are to be recorded from each of the test areas. The patchboard further enables the operator to select the signals that are to be monitored for alarm indication. To minimize errors resulting from unguarded capacitance, shielded, telephone-type (ring-tip-sleeve) jacks and plugs are used at the patchboard. Figure V-10 shows how unguarded capacitance at the patchboard and a common-mode voltage between channels can result in a differential error signal. The telephone-type jacks and plugs are gold plated to minimize thermal errors.

d. Calibration Sub-System

Included in the system is a means of automatically providing a voltage calibration through the low-level multiplexer, and/or amplifiers, and ADC. A five-point automatic calibration system is provided (0%, +80%, 0%, -80%, 0%). At the start of each run or test, the staircase calibration signal is logged for all input channels. The calibration switches are automatically stepped together. The amplifier gain switch automatically selects the proper value of the plus and minus 80% calibration signal. This method prevents overdriving and saturation of the amplifier. This would happen if, for example, the 40-millivolt calibration signal were erroneously applied to an amplifier the range of which was ∓ 5 millivolts. (Refer to Figure V-11.) Calibration can be commanded locally at the test sites or remotely from the central data unit or from the computer. A five-point staircase calibration run is made on the strain gage conditioning cards simultaneously to the voltage calibration of the thermocouple channels. As previously described, shunt calibration-resistors are provided for each strain gage transducer. The use of shunt calibration for bridge-type transducers calibrates the bridge, its power supply and the system. The voltage substitution method calibrates only the system. From the calibration records, the computer can readily correct for any system offsets or non-linearities.

e. Strain Gage Channel Amplifiers

Thirty-six ASTRODATA Model TDA-880 differential amplifiers are provided on an amplifier-per-channel basis for the high accuracy strain gage channels. This type of amplifier provides good accuracy, linearity, and stability and has the advantage of offering excellent common-mode rejection over a wide range of common-mode voltage frequencies and over a wide range of transducer source resistance unbalances. Each strain-gage amplifier used in this system is provided with two outputs; one is routed to the high-level multiplexer, the other is routed to the input patchboard, where it is used in conjunction with the strain gage monitors. The Model TDA-880 differential amplifier has an accuracy of 0.02% of full scale. Included in the amplifier are four filters. Each filter has two real poles and provides a roll-off of 12 db per octave. The desired filter is selected by means of a front panel switch. Filter cut-off frequencies of 2.5, 5, 20, and 100 cps are provided. The TDA-880 amplifier has a chopper input section in which the input voltage is chopped and coupled, through a transformer, to an amplifier. At the output of the amplifier, a transformer couples the signal to two demodulator circuits. One demodulator circuit provides positive feedback to the input of the amplifier to achieve a potentiometric input circuit. The other demodulator delivers the output. Since there is no resistive connection between the input circuit and output, the leakage resistance is in the order of thousands of megohms. Figure V-12A shows the basic arrangement of this amplifier. The effective capacitive coupling of the input and output circuits is kept as low as possible by the use of a guard shield. This guard shield is grounded at the transducer.

f. Low-Level Multiplexer

A 200-channel low-level multiplexer is provided at the central data unit. Assignment of input signals to multiplexer channels is made at the input patchboard. The multiplexer is a solid-state, high-speed, precision electronic time-division commutator that sequentially connects a number of low-level inputs to a common output bus. It has inherent high transfer accuracy and low noise-level, with inputs in the millivolts region, even under rigorous conditions of vibration and temperature. The low-level multiplexer switch used in this system features extremely low offset, is guarded, and also contains a shunt switch to inhibit crosstalk. The most useful advantage of the multiplexer is its ability to perform high-speed data-gathering without the need of a signal conditioning amplifier for each input. The net result is a significant increase in system reliability as well as a saving in space and cost. The organization of the low-level multiplexer is shown in Figure V-13. Primary low-level switching consists of ten groups of two parallel multiplexer switches feeding into an input amplifier. Ten sets of 20 switches are thus used to commutate all 200 channels. Each set of switches has its own amplifier. The use of multiple amplifiers permits a variety of gain settings to be used, thus providing the required sensitivity on all channels. Under computer control, groups of 20 channels are selected by the computer for processing. Thus, ten such groups of 20 low-level-multiplexed channels each are available.

g. Multiplexer Amplifiers

Ten ASTRODATA Model TDA-885 potentiometric, chopper-stabilized input amplifiers are used with the 200-channel multiplexer. In this amplifier the input and output connections are completely isolated from each other. Input-output isolation is achieved by the use of an output isolator as shown in Figure V-12B. The TDA-885 amplifier requires the use of a floating, guarded power supply. After amplification to the full output level, the isolator chops the waveform and couples it, through two transformers, to a demodulator. Here it is filtered and delivered to the load. By operating the isolator at a high level, at 35 kilocycles (typical), transistor choppers can be used. This improves the frequency response of the overall amplifier to approximately 5-kc at the 3-db point. At the same time, the potentiometric input circuit is retained to achieve a high input resistance. Excellent common-mode rejection is also achieved. One important advantage of this circuit is that overload protection can be applied to the input amplifier without having to include the isolator in the overload protection feedback circuit. A second advantage is that the output circuit can be floated from both input and chassis or power ground so that the output currents of several amplifiers do not have to return through a common ground path.

h. Strain Gage Monitoring Sub-System

The strain gage monitoring sub-system included at the central data unit compares the output from twelve strain gage amplifiers to a voltage derived from a decimally-set multi-turn potentiometer. The outputs from the strain gage amplifiers are returned to the input patchboard. Here, any twelve outputs are selected for monitoring. (Utilizing the outputs from the differential amplifiers of the strain gage enables the use of a single-ended monitor sub-system. A floating monitor sub-system would be required if it were necessary to monitor directly the output of the strain gage conditioning cards.) The amplified output of the signal of the selected strain gage channel (± 5 volts full scale for all ranges) is compared to the signal from a digitally-set multi-turn potentiometer, as shown in Figure V-14. Should the input signal exceed the limit setting on the potentiometer an alarm is indicated. Individual alarm contacts and lights are provided for each channel at each wind tunnel.

i. High-Level Multiplexer

A transistor multiplexer, similar to the low-level multiplexer, is used as the high-level multiplexer switch. Only single-conductor switching is needed at the high-level multiplexer as all data is referenced to system ground. These switches are used to connect the outputs of the differential input signal amplifiers to the analog-to-digital converter.

j. Analog-to-Digital Converter

A single analog-to-digital converter is used in the central data unit. The ADC is a high-speed, bi-polar (ones complement) analog-to-digital converter. Full scale is ± 4096. The conversion rate is 10,000 measurements per second. The ADC, by a method of successive approximations, determines the digital weight of the analog input voltage. The result is read as 13 bits of binary data. Negative numbers are shown as "ones complement". A current proportional to the input signal is applied to the summing junction of the comparator amplifier. To provide offset binary or "ones complement" coding, a current equivalent to the weight of and of opposite polarity to the most significant binary bit, is also applied to the summing junction. Operation is as follows: The most significant bit in the register is turned on. The digital-to-analog converter, controlled by the register, applies to the comparator summing junction a current proportional to the weight of that bit. The output of the comparator amplifier is tested (or "strobed"). If the test current is greater than the input currents, the bit is rejected. If the input currents are greater, the bit is accepted. Similarly, the next-most-significant bit is tested and accepted or rejected. This process of testing and accepting or rejection continues until the least significant bit has been tested. At this time an "end of conversion" pulse is generated and the ADC is ready to accept new information.

k. Decimal Data Display

A display system is provided to enable any analog channel to be presented in digital form at any of the sites. Each test site is equipped with a three-decade thumbwheel display-channel selector, as indicated in Figure V-15. The channel number address of the channel selected for display is transmitted from the test site to the central data unit via digital transmission lines. In the central data unit display control unit, the selected address is compared to the address of the channel that is currently undergoing analog-to-digital conversion. When coincidence is detected, indicating that the desired channel is undergoing conversion, the display control unit will cause the digitized output from the ADC to be transferred, via a logical gating structure, to a binary-to-decimal converter (BIDEC). The BIDEC converts the digitized data to "three-decade BCD and SIGN" format. The BCD output from the BIDEC is loaded into a storage register associated with the requesting test site. The BCD representation of the measured value is transmitted to the test site via 13 parallel digital transmission lines. At the test site, these lines are terminated in lamp drivers which, in turn, provide a three-decade-and-sign decimal display. A control is provided at each test site to establish the interval at which the test site will request up-dating of the decimal data display. In this manner, the test site operator may adjust the display time in the range from a nominal 100 milliseconds to a nominal one second. An important feature of this arrangement is that only a single measurement standard exists within the system. All calibration and adjustment measurements are made with the same analog-to-digital converter that is employed during recording runs.

l. Digital Input Registers

Six 36-bit words may be entered into the system at each test site. Under computer control, this information is gated into the registers at the central data unit. Digital input information may be provided by contact closures. An "on" or "1" bit may be represented by -6 volts and an "off" or "0" bit may be represented by 0 volts.

m. Digital Gates

These gates are solid-state switches. These switches connect the digital computer in the central data unit, under computer control, to the output of the ADC, the digital registers, and various code words.

3. Operation

a. Computer Control

Control of the system is from an on-line digital computer. The primary function of the central data unit is to maintain and supervise communication between a selected sub-system and the general purpose digital computer at the central facility. The central data unit provides the necessary data routing as well as the required voltage interface adapters between the intersite digital transmission lines and the computer's input/output interface. A comprehensive control scheme is provided wherein the stored program within the general purpose computer exercises complete control over the data acquisition system. Provisions are made whereby an off-line sub-system may be operated independently of the computer, under manual control, for calibration and check-out purposes.

Input data originating from the data acquisition sub-system is directed to the computer interface control unit. This control unit, in turn, communicates with magnetic core storage within the computer via one of its high-speed input/output channels. Control pulses from the computer to the data acquisition sub-system are initiated via input/output transfer instructions. The various input/output transfer pulse-pair lines are directed from the computer to the site selector, where voltage interfacing is accomplished and the control pulses from the computer are routed to the selected wind-tunnel site. Edited data from 12 selected channels may be directed from the computer, through the input/output register, to a high-speed paper-tape perforator at the wind tunnel site via the site selector. The control of this data-change is accomplished via regular "load input/output register" instruction and "input/out transfer" instruction sequences. The input/output transmission techniques utilized within the computer is a "bus" system wherein data is applied to 18 parallel buses that are common to all input/output devices. After the data is stable, a unique control pulse strobes the information from the buses into the selected input/output device. The system utilizes this standard input/output exchange technique for transfer of information from the computer to the paper tape perforator, as well as to the transfer of control operands from the computer to the data system, in order to establish input channel selection, sampling rate and mode control. Figure V-16 shows the transfer paths of information from the test sites and central data unit to the computer.

The computer provides:

1) Programmable priority of data acquisition assignments.
2) Automatic execution (command) of the highest priority request.
3) Completion of one request before assigning a new request (except the end-of-logging request).
4) Request for:
    a) Run change
    b) Logging of data. It is possible to select for logging, any or all of ten groups of 20 multiplexed thermocouple channels for any or all of four groups of 10 strain gage channels.
    c) End of logging.

Through computer programming, the following logging modes are available:

1) Quasi-steady state.
    a) One to 20 samples per channel, selected for arithmetic averaging by computer.

b) One to 10 samples per second per channel.

c) Twelve programmable channels transmitted to the computer output punch in the test output area.

2) Continuous.

The basic sampling rate of the system is computer-selected at 2000 to 5000 samples per second. Logging is terminated by a stop request to the computer.

3) Periodic.

The selectable scan rate is 100, 50, 20, 10, 1, and 0.1 scans per second. (The channels are selectable in groups of 10 or 20 channels.)

4) External Timing.

a) Timing determined by an external source for sub-commutating.

b) Ability to select up to three channels in the scan cycle to enter a sub-system scan, wherein the system stops on the channel and receives a succession of signals from a single source.

5) Logging signal.

A voltage-level-type signal is made available at the test area to designate that logging is in process.

b. System Self-Checker

An automatic system-checker is included in each test area sub-system. With this feature, the system can be automatically checked, assuring the operators that it is working within its specified accuracy. Figure V-17 shows the arrangement of the automatic system-checker. An input relay is provided to switch the system's inputs from their data source to a calibration signal source. The relay in the "system check" mode applies a known voltage to the input. The system is then used to measure and digitize the calibration signal. The digital value of this signal is checked at the output of the analog-to-digital converter to verify that the signal has indeed been digitized correctly. A tolerance switch is provided in the check unit to set the maximum allowable deviation or tolerance permitted between the calibration signal and the digital output; i.e., ± 1 bit, ± 2 bit, etc. The system is then operated and the digital readings from the system are compared to the calibration value.

If the digital reading exceeds or is less than the expected reading and the tolerance, an output error pulse is generated. The detection of an error will halt the system, enabling an investigation to be made to determine the cause of the error. Lamps associated with the multiplexer and the system's programming enable the source of trouble to be rapidly pin-pointed.

c. Summary

Near-limitless acquisition control options are available to the system user. These control features employ straight-forward computer programming techniques. Consequently, later modifications or system expansion may be conveniently accommodated. Photographs of the system installation at JPL are presented in Figures V-18 through V-20.

4. Coordination

Effective automatic data processing is highly dependent upon good coordination among the various organizational elements involved. The idea that because a system is automated there is little need for coordination is an illusion. The casual coordination which might have sufficed for manual data reduction produces confusion and inefficiency when applied to automatic processing methods. In fact, the more automatic the data handling becomes, the more extensive the coordination must become. Reduction problems and the usual assortment of details must be resolved as far in advance as possible. Proper coordination does not cease after initial planning, but continues for the duration of the test program with representatives from the test and data processing organizations meeting regularly to discuss program progress. The instrumentation and test project engineers should be present during the quick-look phase of the data processing; the testing engineer for making selections of parameters scheduled for computer processing, the instrumentation engineers for supplying information concerning the transducers and acquisition system. The instrumentation engineer can also be of special assistance to the data processing group by relaying information regarding acquisition difficulties such as oscillator drift, excessive noise, etc. If acquisition difficulties have been experienced and the reduction group is not informed, considerable time might be wasted in the futile search for malfunctioning reduction equipment.

A project group composed of members from the participating function sections has been formed for the operation of the JPL wind tunnel data system.

The responsibilities for the function organizations are unaltered, that is, they are still reponsible for maintaining professional competence, salary administration, training, promotions, and the complaints of the assigned personnel. The core of the project group (hereafter referred to as the data system team or team) is composed of an instrumentation engineer, data system engineer, and a system programmer. In addition, representatives from the Facility Operations and Test Projects Groups are assigned. The chief of the Aerodynamic Facilities Section heads the team. This position is more than titular. Since responsibility is not direct to the team head in all cases, he must direct the team through mutual cooperation and consent. When conflict exists which cannot be resolved by mutual consent, it is passed on to the appropriate function organization supervisor for solution.

Instead of tightly-defined areas of responsibilities, areas of principal interests are defined and the promotion of team effort is urged to accomplish better total performance. This concept is illustrated in Figure V-21. The areas of principal interest for the instrumentation engineer, data systems engineer, and systems program engineer are as follows:

Instrumentation Engineer

Operation

Determine measurement requirements.

Select the transducer and signal conditioning equipment required.

Set up and check out the measurement system.

Maintenance

Maintain sensors.

Maintain conditioning equipment in the input areas.

Maintain standards.

Quality Control

Provide standards and secondary standards.

Perform accuracy checks.

Instrumentation Development

Analyze wind tunnel instrumentation performance and requirements.

Survey state-of-the-art for instrumentation improvements.

Adapt standard items for specific use.

Develop special devices.

Data System Engineer

Operation

Check out hardware system for correct operation prior to system being released for use.

Verify and isolate area of fault if one is suspected.

Maintain equipment operating log.

Design

Analyze system performance and operation.

Plan and supervise all system equipment modification.

Survey state-of-the-art for system improvement.

Maintenance

Maintain all system equipment other than the sensors and conditioning equipment located in the input areas.

Maintain failure records and corrective measures record.

System Program Engineer

Software

Provide basic system operation software.

Provide computer and computer/data-system diagnostic and system performance analysis routines.

Provide "standard" data processing routines

for use within basic data system (PDP)

other computers as required

service routines to insure data.

Formulate and submit "special" data processing problems to central data program analysis group.

Problem and System Analysis

Analysis of computing requirements of each test project in conjunction with test projects representative.

Develop overall data processing plan where multi-computer computing is required.

Operations

Schedule operation of PDP

program check out

off- and on-line operation.

Maintain log of operation performance.

Coordination of data processing on other machines.

System Program Engineer (continued)

Data Processing Development

Survey state-of-the-art for processing improvements.

Maintain cognizance of central processing equipment and procedures.

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TABLE I-1.

History of JPL Wind Tunnel

Data Systems

Year	Tunnel Operation	Data Acquisition	Data Reduction	Data Presentation
1948	Hand set conditions	Hand-written on data sheets Hand plotted raw data	Hand computed with desk calculators	Hand plotted
1949	Remote angle of attack			
1950				
1951			IBM 604	
1952	Remote roll support	Hand punched on keyboards, IBM punch		
1953	Remote model surface deflections		IBM CPC	EA keyboard or punched card data plotter
1954			Electrodata 220	
1955		Coleman digitizers on self-balancing potentiometers, Flexowriters, punched tape, 12-channel automatic raw-data plotter		
1956				JPL 9-channel paper tape feed plotter
1957	Remote diffuser Control			
1958				
1959	Automatic T_o control			
1960				
1961	Programmed angle of attack			
1962				Stromberg Carlson 4020
1963		Astrodata Integrated System, magnetic tape	PDP-1, IBM 7090	

TABLE III-1. ERROR EVALUATION

Error Source	Type*	Error % Force	Pressure	Temp.	Transient HT
Aerodynamic uncertainty and similarity (not included in totals below)	S	1.00	2.00	1.00	6.00
Flow Conditions	R	.10	.10	.10	.10
Transducer					
Mechanical Quality	S	.25	.25	.20	.30
Calibration Quality	S	.05	.05	.10	.10
Amplifier	R	.01	.01	.02	.02
Electronic Noise	R	.02	.02	.02	.10
Mechanical Noise	R	.10	.10	---	---
Scanner	R	.01	.01	.01	.01
ADC	R	.01	.01	.01	.01
Technique	S	.05	.05	.05	.50
Systematic Error		0.35	0.35	0.35	0.90
Random Error		0.25	0.25	0.16	0.24
RMS Random Error		0.14	0.14	0.11	0.14
Probable Error		0.49	0.49	0.46	1.04
Maximum Possible Error		0.60	0.60	0.51	1.14

* S represents systematic errors; R represents random errors.

TABLE III-2

INPUT QUANTITIES

KIND OF DATA	SIGNAL SOURCE	UNITS	SIGNAL RANGE	RECORDING ACCURACY	SCANNING RATE	OUTPUT DIGITAL COUNTS	NO. OF CHANNELS
A. Tunnel Parameters							
Mach No.	Digitizer	-	-	-	1/scan	+9999	< 1
Supply Press.	Transducer	MV	0-5	(±0.1% of Read.	"	"	1
Supply Temp.	Thermocouple	MV	0-50	±½ Digit)	"	"	1
Test Sect. Static Press.	Transducer	MV	0-5	"	"	"	1
Test Sect. Pitot Press.	"	MV	0-5	"	"	"	1
Reynolds No.	Digitizer	Coded	-	-	"	99	< 1
Kind of Freestream Gas	"	"	-	-	"	99	"
Air On or Air Off	"	"	-	-	"	9	"
Run, Point	"	"	-	-	"	99999	"
Tunnel	"	"	-	-	"	9	"
B. Model Parameters							
Angle of Attack	Potentiometer	MV	0.25	±0.003 MV (±0.01°)	"	±9999	1
Angle of Roll	"	"	"	±0.003 MV (±0.1°)	"	"	"
Angle of Yaw	"	"	"	"	"	"	"
Control Surface Deflect.	"	"	"	±0.003 MV (±0.05°)	"	"	"
Configuration	Digitizer	Coded	-	-	"	99	< 1
Jet On or Jet Off	"	"	-	-	"	99	"
C. Force Test							
Normal Force or Lift	Strain Gage	MV	±5	(±0.1% of Read	100 Chan/Sec	±9999	1
Side Force	"	"	"	±½ Digit)	"	"	"
Chord Force or Drag	"	"	"	"	"	"	"
Pitching Moment	"	"	"	"	"	"	"

TA[illegible]II-2 (Con'd)

INPUT QUANTITIES

KIND OF DATA	SIGNAL SOURCE	UNITS	SIGNAL RANGE	RECORDING ACCURACY	SCANNING RATE	OUTPUT DIGITAL COUNTS	NO. OF CHANNELS
Yawing Moment	Strain Gage	MV	±5	(±0.1% of Read	100 Chan/Sec	±9999	1
Rolling Moment	"	"	"	±½ Digit)	"	"	"
Panel Load	"	"	"	"	"	"	"
Hinge Moment	"	"	"	"	"	"	"
Spares	"	"	"	"	"	"	4
D. Pressure Test							
Model Orifices	Transducer	MV	0-5 }	(±0.1% of Read	20 Chan/Sec	+9999	150
Freestream Press. Trace	"	"	"	±½ Digit)	100 Chan/Sec	"	1
Probe Position (X,Y,Z)	Potentiometer	"	0-25	"	"	±9999	3
E. Temperature Test							
Model Temperatures	Thermocouple	MV	-10 to +50 }	(±0.1% of Read	3000 Chan/Sec	±9999	150
Freestream Temp.	"	"	"	±½ Digit)	20 Chan/Sec	"	1
Freesteam Temp. Trace	"	"	"	"	100 Chan/Sec	"	"
Probe Position (X,Y,Z)	Potentiometer	"	0-25	"	"	"	3
Time	Scan. Equip.	-	-	-	20 Chan/Sec	-	1
F. Dynamic Stability Test							
Angle of Attack	Photo Cell	V	1 V. Pulse at Maximum Freq. of 20,000 Pul-ses per sec.	±0.05% in # of Counts ±½ Digit	20,000 Pul-ses per.sec	10^8 cnts.	1
Time	Scan. Equip.	-	-	"	-	-	1
G. Vibration Test							
Panel Flutter	Variable Inductance Or Capacitance Or Photocell	MV or V	1 V. Pulse	±0.05% in # of Cnts. ±½ Digit	20,000 pul-ses per sec	10^8 cnts.	1
Time	Scan. Equip.	-	-	"	-	-	1

TABLE III-3 DIGITAL INPUTS

		No. Of Digits
Run Information		
Prologue		1
Tunnel		1
Type of data		1
Test no.		4
Run		4
Program no.	Computer Control	1
Matrix no.	Computer Control	1
Configuration	Computer Control	1
Tare no.	Computer Control	1
Display		1
Logging		1
Angle of attack	Model Attitude (When constant for a run)	1
Angle of roll	Model Attitude (When constant for a run)	1
Angle of yaw	Model Attitude (When constant for a run)	1
Axial location	Model Attitude (When constant for a run)	1
Spares		15
Point Information		
Tunnel (same as "Run Inform.")		1
Type of point		1
Run no. (same as "Run Inform.")		4
Point no.		4
Mach no.		4
Spares		10
	Total digital input	60

TABLE IV-1. COST COMPARISON

		A	B	C		D	E
		Option (2)	Option (2)	Option (1)	Option (2)	Option (2)	
1	Direct Material						
	Purchased Parts	44,000		143,060		140,829	260,715
	Subcontract Parts	104,050					(10,600)
	Other	(-800)	(16,000)	(10,800)	(10,800)	(28,400)	1,568
2	Engineering Labor						
	Hours	2,710		5,960		3,934	4,994
	$	13,812		25,654		19,700	26,862
	Burden %	56	115	132	132	125	100
	Burden $	7,711		33,863		24,529	26,862
	Sub Total	21,523		59,517		44,229	53,724
3	Manufact. Labor						
	Hours	5,350		5,304		5,453	5,195
	$	14,600		15,978		14,100	11,620
	Burden %	56	115	132	132	128	100
	Burden $	8,200		21,091		18,023	11,620
	Sub Total	22,800		37,069		32,123	23,240
4	Customer Service			13,759	13,759	4,750	(3,000)
5	Miscellaneous						
6	General & Admin. %	36	25	29.5	29.5	21	10
	General & Admin. $	31,796		75,053		48,758	33,985
7	Profit %	10	10	10	10	10	~7
	Profit $	22,416		32,947		26,200	26,168
8	Proprietary Items	126,918				70,000	
	TOTAL (Per Proposal)	373,503	374,243	362,417	341,331	360,813	400,000
	ADJUSTED TOTAL	373,000	390,000	373,000	352,000	389,000	413,600

TABLE IV-2

COST ADJUSTMENT

EQUIPMENT INCLUDED IN PROPOSAL

	A	B	C		D	E
T. C. Ref. Junctions	7 x 50	4 x 50	7 x 50		4 x 50	7 x 50
S. G. Power Supplies	52	52	52		36	52
S. G. Bal. & Volt. Adjustment	3	0	0		3	3
Digital Voltmeter	3	0	0		0	0
Filters	4 x 36	4 x 36	51		72	4 x 36
Limit Monitors	36	12	24		24	24
Digital Registers	0	18	0		0	0
Decoders	0	0	1		0	0
Programming	340 Hr.	100 Hr.	430 Hr.		340 Hr.	80 Hr.
COST ADJUSTMENT						
T. C. Ref. Junctions	0	5,770	0		5,529	0
S. G. Power Supplies	0	0	0		2,704	0
S. G. Bal. & Volt. Adjust	-2,400	0	0		-2,400	-2,400
Digital Voltmeter	-8,100	0	0		0	0
Filters	0	0	4,800		9,576	0
Limit Monitors	-3,300	3,300	0		0	0
Digital Registers	6,000	0	6,000		6,000	6,000
Decoders	7,000	7,000	0		7,000	7,000
Programming	0	0	0		0	3,000
360 K SYSTEM						
No. S. G. Power Supplies	40	30	50	52	30	0
No. S. G. Amplifiers	36	24	36	36	26	-
No. Filters	ALL	ALL	ALL	ALL	HALF	0
No. Limit Monitors	24	12	24	24	12	0
Digital Registers	NO	NO	NO	YES	NO	NO
Decoders	NO	NO	NO	YES	NO	NO

TABLE IV-3

STRAIN-GAGE CHANNELS

SHORT TERM (8-HR) ACCURACY (3 σ)

Full Scale (mv)	Company	Filter Cut-Off Frequency (CPS)			
		2.5	5	20	100
2.5	A (2)	.19	.2	.3	.42
	B (2)	.106	.108	.118	.167
	C (1) & (2)	.2	.21	.23	.27
	D (2)	--	.220	--	.236
	E	.450	.450	.450	.450
	Specification	.11	.11	.15	.3
5	A	.11	.11	.20	.23
	B	.083	.085	.088	.122
	C	.15	.15	.165	.19
	D	--	.133	--	.154
	E	.318	.318	.318	.318
	Specification	.10	.10	.13	.2
10	A	.08	.08	.08	.13
	B	.072	.074	.075	.091
	C	.12	.125	.133	.15
	D	--	.102	--	.110
	E	.224	.224	.224	.224
	Specification	.10	.10	.11	.15
30	A	.08	.08	.08	.11
	B	.069	.069	.070	.078
	C	.11	.11	.11	.13
	D	--	.09	--	.10
	E	.142	.142	.142	.142
	Specification	.10	.10	.10	.12
50	A	.08	.08	.08	.10
	B	.067	.068	.069	.075
	C	.10	.10	.107	.12
	D	--	.09	--	.09
	E	.120	.120	.120	.120
	Specification	.10	.10	.10	.10

TABLE IV-4

STRAIN-GAGE CHANNELS

REPEATABILITY

Full Scale (mv)	Company	Filter Cut-Off Frequency (CPS)			
		2.5	5	20	100
2.5	A (2)	.08	.09	.11	.43
	B (2)	.046	.048	.058	.117
	C (1) & (2)	.17	.18	.21	.245
	D (2)	--	.204	--	.229
	E	.426	.426	.426	.426
	Specification	.05	.06	.08	.16
5	A	.06	.07	.09	.26
	B	.033	.035	.038	.072
	C	.12	.13	.14	.165
	D	--	.108	--	.125
	E	.305	.305	.305	.305
	Specification	.05	.05	.06	.10
10	A	.06	.06	.07	.12
	B	.027	.029	.03	.046
	C	.10	.10	.11	.125
	D	--	.065	--	.078
	E	.217	.217	.217	.217
	Specification	.05	.05	.05	.07
30	A	.06	.06	.07	.10
	B	.027	.027	.028	.036
	C	.08	.08	.085	.10
	D	--	.046	--	.055
	E	.132	.132	.132	.132
	Specification	.05	.05	.05	.05
50	A	.06	.06	.065	.09
	B	.026	.027	.028	.034
	C	.07	.08	.08	.09
	D	--	.042	--	.049
	E	.107	.107	.107	.107
	Specification	.05	.05	.05	.05

TABLE IV-5

THERMOCOUPLE CHANNELS

Full Scale (mv)	Company	Short Term Accuracy	Repeatability	
			Low Noise	Standard
5	A (2)	.57	--	.56
	B	.363	.163	.223
	C (1) & (2)	.46	--	.24
	D (2)	.350	--	.296
	E	.208	--	.168
	Specification	.30	.20	.30
10	A	.3	--	.29
	B	.209	.089	.130
	C	.27	--	.16
	D	.225	--	.182
	E	.152	--	.124
	Specification	.15	.12	.15
20	A	.16	--	.16
	B	.138	.058	.078
	C	.175	--	.12
	D	.165	--	.124
	E	.113	--	.093
	Specification	.10	.06	.10
50	A	.09	--	.09
	B	.095	.039	.06
	C	.12	--	.10
	D	.160	--	.119
	E	.081	--	.071
	Specification	.10	.05	.05

TABLE IV-6

SYSTEM CHARACTERISTICS

	A	B	C (1)	C (2)	D	E
Sampling Rate (System)	2 KC	5 to 2 KC	5 KC	2 KC	1.8 KC	2.5 KC
Hi-Level Mult. & ADC Rate	10 KC	10 KC	10 KC	10 KC	20 KC	2.5 KC
Scan Length Control	PDP	PDP	Manual	Manual	PDP	PDP
Scan Rate Control	Manual	PDP	PDP	PDP	Manual	PDP
S.G. Block Length	1 or Seq.	10	Sequential	Sequential	36	1
T.C. Block Length	1 or Seq.	20	Sequential	Sequential	10	1
Calibration Control	PDP	PDP	Manual	Manual	PDP	Manual
Limit Monitor Type	Analog	Analog	Digital	Digital	Analog	Analog
S.G. Ground	Trans.	Trans.	Trans.	Trans.	Trans.	System
T.C. Ground	Trans.	Trans.	Trans.	Trans.	Trans.	System
T.C. Ref. Junct. Shield Blocking	50	10	50	50	50	50
T.C. Ground Blocking	1	1	10-30	1	1	150
Single Channel Display						
Source	ADC	ADC	ADC	ADC	ADC	DVM
Minimum Rate (cps)	0	8.4	21	8.4	7.6	10
External Timing Mode						
Maximum Sampling Rate	100	100	100	100	100	2.5 KC

TABLE IV-7

PROPOSAL EVALUATION SUMMARY

	Wt. Factor	A (2)							B (2)							C (1)							C (2)							D (2)							E						
		a	b	c	d	e	f	Points	a	b	c	d	e	f	Points	a	b	c	d	e	f	Points	a	b	c	d	e	f	Points	a	b	c	d	e	f	Points	a	b	c	d	e	f	Points
Reliability	7	6	6	6	8	8	8	294	8	8	8	7	8	8	329	8	8	8	8	8	8	336	6	8	8	8	8	8	322	6	6	8	8	8	8	308	6	6	6	8	8	8	294
Accuracy	10	6	5	8	7	8	5	390	9	8	10	8	10	8	530	6	6	6	8	8	5	390	6	6	6	8	8	5	390	6	5	6	6	5	5	330	5	5	5	5	5	2	270
Flexibility	4	6	6	8	8	6	5	156	8	8	8	8	8	8	192	8	8	8	8	8	8	192	6	6	8	8	8	8	176	5	6	5	6	8	7	148	8	8	8	8	8	10	200
Ease of Setup	2	8	8	6	6	8	8	88	9	8	8	8	8	8	98	6	6	8	8	8	8	88	7	6	8	8	8	8	90	8	8	6	6	8	8	88	8	8	8	8	8	8	96
Future Growth	1	5	6	6	8	8	8	41	8	6	8	10	8	10	50	8	8	8	8	8	10	50	6	8	8	5	8	8	43	5	6	5	8	8	8	40	8	8	8	8	8	8	48
Computer Utilization	2	-	-	8	8	-	8	48	-	-	10	10	-	8	56	-	-	8	8	-	8	48	-	-	8	8	-	8	48	-	-	6	5	-	8	38	-	-	6	5	-	5	32
Totals								455							578							496							480							429							422

TABLE IV-8

TECHNICAL CAPABILITY EVALUATION SUMMARY

Technical Capabilities	Weight Factor	A		B		C		D		E	
		Rating	Points	Rating	Points	Rating	Points	Rating	Points	Rating	Points
Engineering Concepts											
Analog Techniques	4	5	20	10	40	8	32	8	32	5	20
Digital Techniques	2	8	16	8	16	8	16	10	20	8	16
Computer Programming	1	5	5	8	8	8	8	8	8	5	5
Accuracy	1	8	8	10	10	8	8	8	8	5	5
System Integration & Balance	1	8	8	10	10	8	8	8	8	8	8
Human Engineering	1	8	8	8	8	8	8	8	8	8	8
Reliability											
Self Checks	1	8	8	8	8	5	5	8	8	8	8
Maintenance Aids	$\frac{1}{2}$	8	4	8	4	8	4	8	4	8	4
Derating Equipment	$\frac{1}{2}$	8	4	8	4	8	4	8	4	8	4
Management Concepts											
Quality Control	2	8	16	8	16	8	16	8	16	5	10
Inspection	1	8	8	8	8	8	8	8	8	5	5
TOTAL			105		132		117		124		85

RATING: 10 = Excellent
8 = Acceptable
5 = Marginal
0 = Unacceptable

TABLE IV-9

COMPANY EVALUATION SUMMARY

Ability to Produce	Weight Factor	A		B		C		D		E	
		Rating	Points	Rating	Points	Rating	Points	Rating	Points	Rating	Points
Capacity											
Personnel	1	8	8	10	10	8	8	8	8	8	8
Facilities (Area)	1	8	8	8	8	10	10	8	8	8	8
Facilities (Equipment)	1	8	8	8	8	10	10	8	8	8	8
Financial	1	8	8	8	8	10	10	8	8	8	8
Capability											
Design & Programming	5	5	25	8	40	8	40	8	40	8	40
Manufacturing	5	5	25	8	40	8	40	8	40	8	40
Quality Control	5	5	25	8	40	8	40	8	40	8	40
Standard Products	6	8	48	8	48	8	48	8	40	5	30
Past Performance											
Delivery	2	5	10	8	16	10	20	8	16	5	10
Quality	3	5	15	8	24	8	24	5	15	5	15
TOTAL			180		242		250		231		207
Program Management											
Terms											
Deviations	1	8	8	8	8	8	8	8	8	8	8
Design Approvals	1	8	8	8	8	8	8	8	8	8	8
Test Approvals	1	8	8	8	8	8	8	8	8	8	8
Warranty	1	5	5	10	10	10	10	8	8	5	5
Training	1	5	5	8	8	10	10	8	8	5	5
Liaison	1	8	8	8	8	8	8	8	8	8	8
Documentation	1	8	8	8	8	8	8	8	8	8	8
Management Control	2	5	10	10	20	10	20	8	16	8	16
Subcontract Purchases	1	8	8	8	8	10	10	8	8	5	5
TOTAL			68		84		90		80		71

TABLE IV-10

WIND TUNNEL DATA SYSTEM PROPOSAL

EVALUATION SUMMARY

		POINTS					
		A	B	C (1)	C (2)	D	E
700	Technical Design (A) (Proposal Evaluation)	455	578	496	480	429	422
150	Technical Capabilities (Grasp of Engrng.Problems)	105	132	117	117	124	85
300	Ability to Produce (Capability, Etc.)	180	242	250	250	231	207
100	Program Management	68	84	90	90	80	71
1250	TOTAL	808	1036	953	937	858	785
	Standing	5	1	2	3	4	6
	Cost (Adjusted) (B)	373,000	390,000	373,000	352,000	389,000	413,600
	Standing	2	5	2	1	4	6
	Value Rating $\frac{A}{B} \times \frac{352}{578}$	75.0	90.6	78.1	83.2	67.5	62.5
	Final Standing	4	1	3	2	5	6

TABLE V-1

Co-operating Facilities

Included in Data System Survey

Code No.	Facility and Address	Contact
1a, b	The Aeronautical Research Institute of Sweden Bromma 11, Sweden	Knut Fristedt
2	Aeronautical Research Laboratory Wright-Patterson Air Force Base, Ohio	E. G. Johnson, Chief, ARF Fluid Dynamics Facilities Br.
3a	AEDC, Propulsion Wind Tunnel Tullahoma, Tennessee	R. W. Hensel, Chief PWT
3b, c, d, e, f	AEDC, Von Karman Gas Dynamics Facility Tullahoma, Tennessee	J. Lukasiewicz, Chief VKF
4a, b	Aeronautical Systems Division Wright-Patterson Air Force Base, Ohio	J. P. Doyle, Jr., Actg. Chief ASTEA Aerodynamics Division
5	Astro/Marquardt Corporation 16555 Saticoy, Van Nuys, California	K. L. Thornbury, Mgr. Test Facilities Section
6	Ballistic Research Laboratories Aberdeen Proving Ground, Maryland	C. C. Bush, Chief Operations Section, SWT Branch
7a, b, c, d	Boeing Company, Aero-Space Division P. O. Box 3707, Seattle 24, Washington	J. H. Russell (50-82) Chief Wind Tunnel Engineer
8a, b	Caltech Jet Propulsion Laboratory 4800 Oak Grove Dr., Pasadena, California	R. E. Covey, Chief Aerodynamic Facilities
9	Chance Vought Corporation P. O. Box 5907, Dallas 22, Texas	R. C. McWherter, Chief Wind Tunnel Laboratories
10a, b	Cornell Aeronautical Laboratory, Inc. P. O. Box 235, Buffalo 21, New York	J. F. Martin, Asst. Hd. Applied Hypersonic Res. Dept.
11	David Taylor Model Basin Aerodynamics Laboratory, Washington 7, D. C.	S. DeLos Santos, Head Gas Dynamics Division
12	Douglas Aircraft Co., Missile and Space System Div., 2332 E. El Segundo Bl., El Segundo, Calif.	J. S. Murphy, Chief Aerophysics Laboratory
13a, b	General Dynamics/Convair P. O. Box 1950, San Diego, California	W. T. Mac Carthy, Chief Aerodynamics Laboratories
14a, b, c	Grumman Aircraft Engineering Corp. Bethpage, Long Island, New York	W. Gander, Head Aero Test Operations
15a	Lockheed-California Company P. O. Box 551, Burbank, California	G. Sim, Dept. Mgr. Wind Tunnels
15b	Lockheed Missiles and Space Company 3251 Hanover St., Palo Alto, California	D. Bershader, Sr. Scientist Physical Sciences Lab.
16	Massachusetts Institute of Technology NSF, 560 Memorial Drive, Cambridge 39, Mass.	W. F. Byrne Aerophysics Laboratory

TABLE V-1 (cont'd.)

Code No.	Facility and Address	Contact
17a, b	McDonnell Aircraft Corp. P. O. Box 516, St. Louis 66, Missouri	F. M. Keyes, Grp. Mgr. Polysonic Wind Tunnel
18a, b	National Aeronautical Establishment Montreal Road, Ottawa, Ontario, Canada	J. W. Tanney Aerodynamics Laboratory
19a, b	NASA Ames Research Center Moffett Field, California	S. J. DeFrance, Director
20a, b	NASA Langley Research Center Langley Station, Hampton, Virginia	F. L. Thompson, Director
21	NASA Marshall Space Flight Center Huntsville, Alabama	J. Heaman Wind Tunnels
22	Naval Ordnance Laboratory White Oak, Silver Spring, Maryland	R. K. Lobb, Pgm. Chief, Aeroballistics
23	North American Aviation, Inc. Columbus, Ohio	M. E. Stevens, Chief Aerodynamics Laboratory
24	North American Aviation, Inc., L. A. Division International Airport, Los Angeles 45, Calif.	W. Daniels, Jr., Chief Aero-Thermo Laboratory
25	Northrop Corporation, Norair Division 1001 E. Broadway, Hawthorne, California	P. F. Jensen, Chief Research Labs. 3740/33
26	Ohio State University Aerodynamics Laboratory, Columbus 10, Ohio	R. E. Thomas, Asst. Supv., Aero. Lab.
27	Republic Aviation Corporation Farmingdale, Long Island, New York	A. Cravero Wind Tunnel Project Engineer
28a, b	Sandia Corporation Sandia Base, Albuquerque, New Mexico	R. C. Maydew, Supv. Experimental Aerodynamics
29a, b	United Aircraft Corporation Research Laboratories, East Hartford 8, Conn.	G. D. Dickie, Jr., Head Test Facilities

TABLE V-2

Low Speed Systems

Small

Code No.	Facility	Scan Rate (words/sec.)	Max. No. Channels	Cost Thous. of Dollars	Yr. of Initial Op.	Acquis. System Mfg.	Computer* Mfg.
6	Ballistic Res. Lab	0.9	8	200	1955	HGB	Central
12	Douglas Santa Monica	1.4	16	110	1958	Datex	IBM 1620
28b	Sandia	1.66	10	50	1956	Datex	Central
28a	Sandia	1.66	13	45	1959	Datex	Central
7b	Boeing Supersonic	1.66	14	120	1957	Giannini	Central
7c	Boeing Hypersonic	1.66	82	30	1957	Datex	Central
18b	NAE - Canada	5	27	60	1960	Datex	IBM 1620
7a	Boeing Transonic	2.5	15	64	1955	L and N	Central
21	NASA - Marshall	4	6	50	1957	Consol.	Bendix G15
14a	Grumman	4	25	15	1962	Own	Central
18a	NAE - Canada	12	10	50	1957	MH	Bendix G15
1a	Aero. Res. Inst. - Sweden	14	14	40	1957	Own	IBM 1620
29b	United Transonic	20	12	40	1955	Giannini Datex	Central
20a	NASA - Langley Unitary	20	40	165	1961	Own	Central
10a	Cornell Transonic	26	46	120	1954	Own and Consol.	Burroughs 204
1b	Aero. Res. Inst. - Sweden	50	56	20	1962	Own	IBM 1620
4a	ASD. Wright Fld. SWT	-	10	40	1956	T and C	Central
14b	Grumman Supersonic	-	52	10	1961	Consol.	Central
16	MIT	-	46	150	1957	Own	Bendix G15
26	Ohio State	-	30	20	1956	Own	EA
			Large				
8a	Caltech - JPL (old)	6	123	150	1957	Own	Burroughs 205
19a	NASA - Ames Unitary	10	300	120	1962	Beckman 210	MH-H-800
13a	Gen. Dyn. - Convair	10	434	80	'46, '61	Own	Central
3b	AEDC - VKF	20	200	325	1954	ERA	ERA 1102
3a	AEDC, PWT	20	400	1,100	1960	Own	ERA 1102
14c	Grumman MPRS	-	150	41	1957	FP	Central

*Used primarily (50% or more) for wind tunnel data reduction.

TABLE V-3

High Speed Systems

Small

Code No.	Facility	Scan Rate (words/sec.)	Max. No. Channels	Cost Thous. of Dollars	Yr. of Initial Op.	Acquis. System Mfg.	Computer* Mfg.
11	DTMB, USN	533	50	250	1960	Beckman 210	Central
23	NAA-Columbus	800	80	200	1959	Beckman	Central
3f	AEDC-VKF 50" Hotshot 1	10,000	30	50	1962	Own	Central
2	ARL, Wright Field	10,000	40	133	1962	Consol.	Central
29a	United Subsonic	11,000	20	300	1958	Epsco	Central
15b	Lockheed MSC Hotshot	-	18	15	1960	-	Central
7d	Boeing Hotshot	-	48	100	1959	Consol.	Central
3d	AEDC-VKF 100" Hotshot	-	50	70	1962	Consol.	Central
3e	AEDC-VKF 50" Hotshot 2	-	50	70	1958	Consol	Central
17b	McDonnell HIT	-	50	110	1963	MH	Central
10b	Cornell WS Hyp.	-	70	- 0	1962	Consol.	-
			Large				
27	Republic	100	100	70	1962	Sys. Donn.	Central
5	Marquardt	400	100	300	1955	Own	Alwac III E
4b	ASD, Wright Field Hyp.	400	100	110	1959	Consol.	Central
13b	Gen. Dyn. Convair	400	125	150	1958	Consol.	IBM 1401
9	Chance Vought	1,000	120	150	1958	Beckman	Beckman EASE
17a	McDonnell, PSWT	1,572	125	290	1959	Consol.	Central
3c	AEDC-VKF, Ht. Trs.	2,400	121	240	1960	Beckman 210	IBM 7070
20b	NASA - Langley Central	2,400	240	435	1960	Beckman 210	Central
19b	NASA - Ames 3.5 HWT	2,500	100	375	1960	Beckman 210	Central
24	NAA Trisonic	3,600	120	100	1957	Own	Alwac III E
22	Nav. Ord. Lab	5,000	102	250	1961	Epsco	Central
8b	Caltech - JPL (new)	5,000	258	360	1963	Astrodata	PDP-1
15a	Lockheed, California	7,000	120	250	1960	Beckman 210	IBM 1401
25	Northrop - Norair	15,000	250	160	1963	Astrodata	Central and 162

*Used primarily (50% or more) for wind tunnel data reduction.

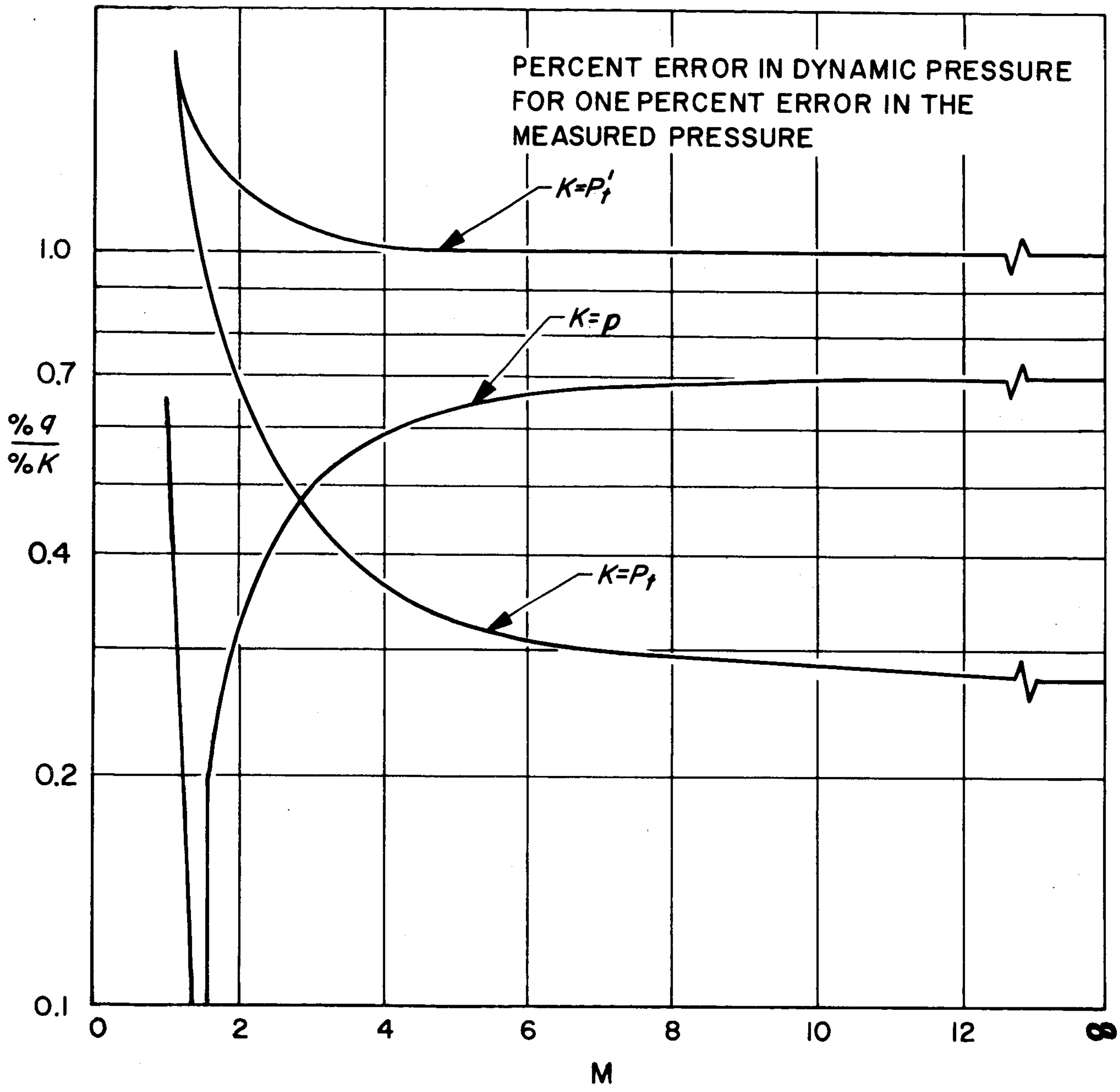


Fig. III-1. Percent error in dynamic pressure for one percent error in the measured pressure

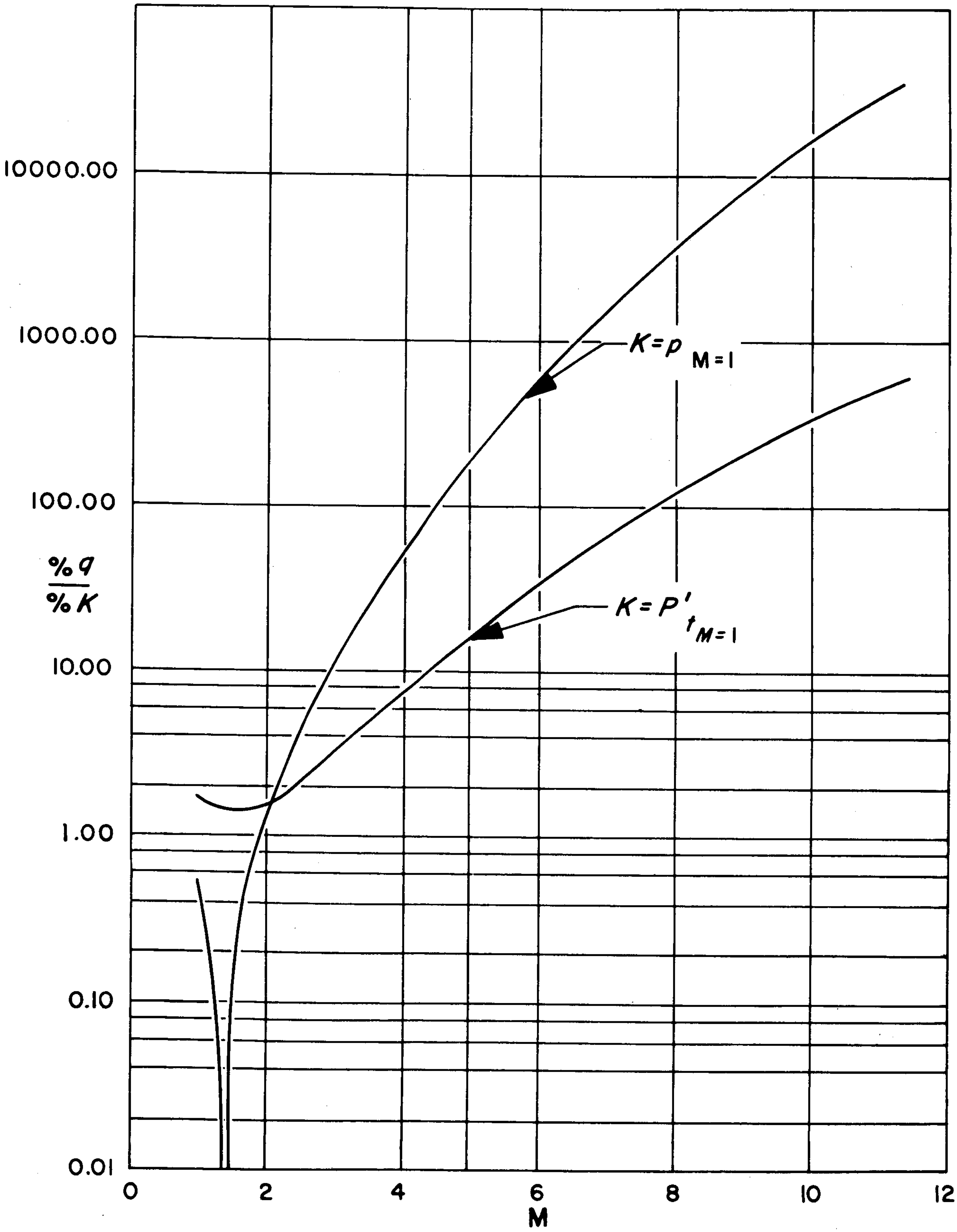


Fig. III-2. Percent of error in dynamic pressure for one percent error in the capacity of the transducer (P_t = constant)

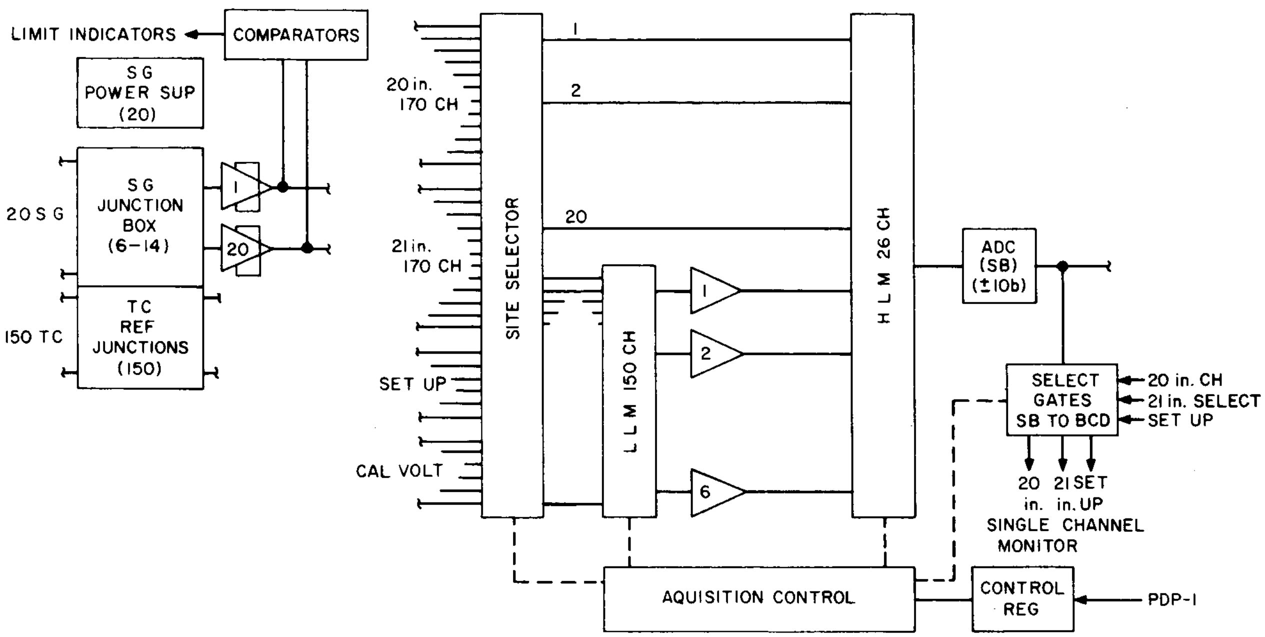


Fig. IV-1. Company A, No. 2, analog system

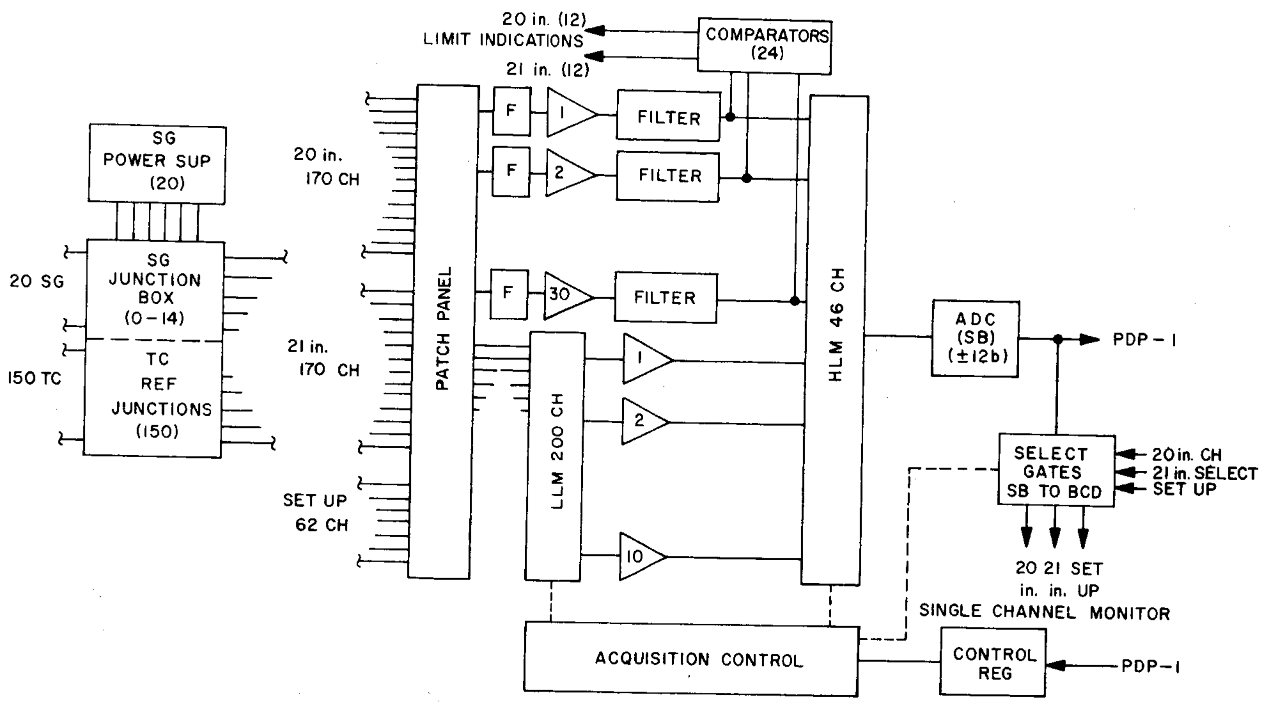


Fig. IV-2. Company B analog system

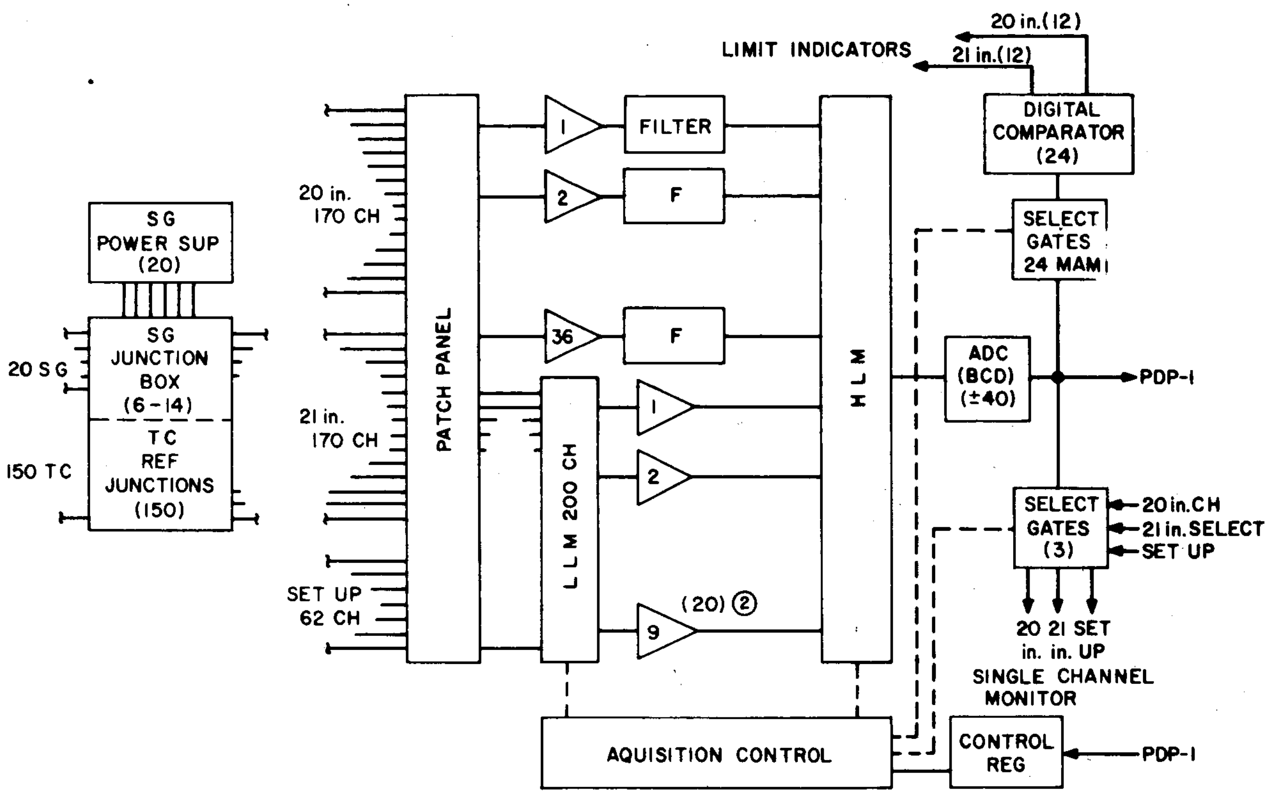


Fig. IV-3. Company C, No, 1 and 2, analog system

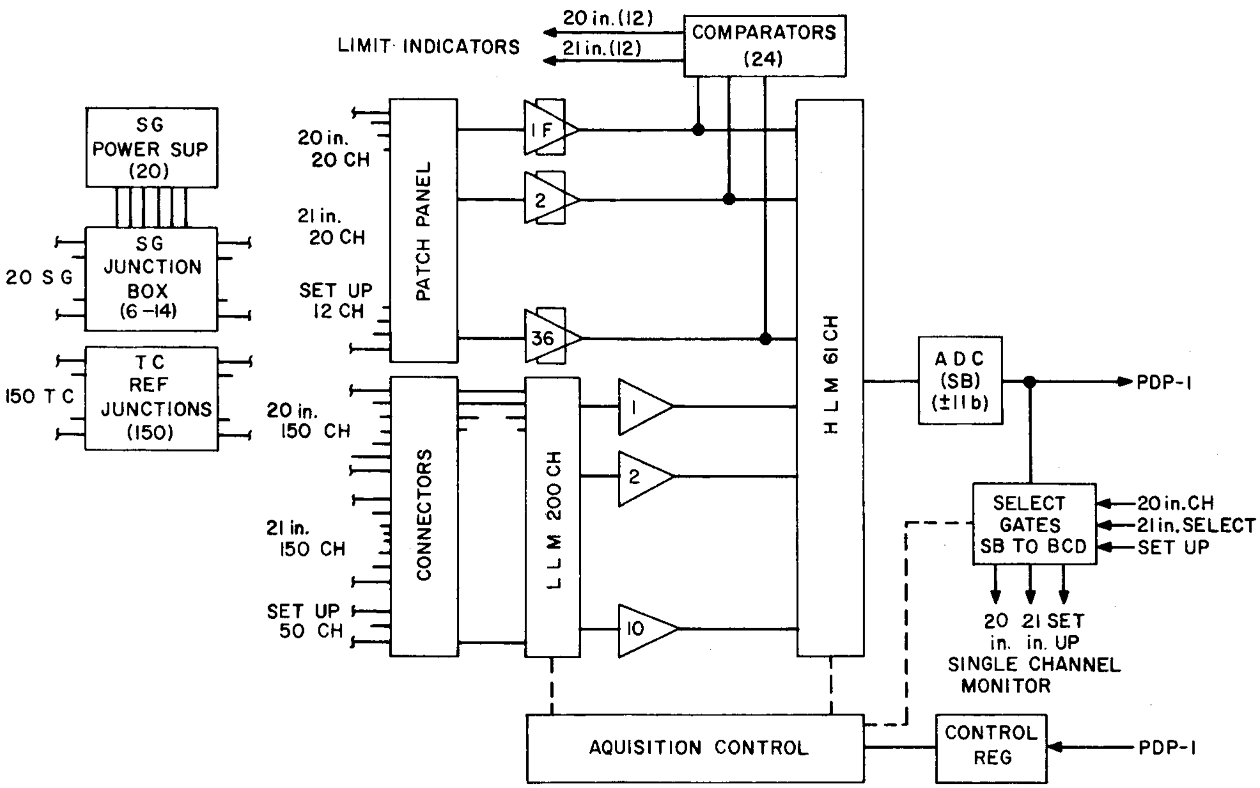


Fig. IV-4. Company D, No. 2, analog system

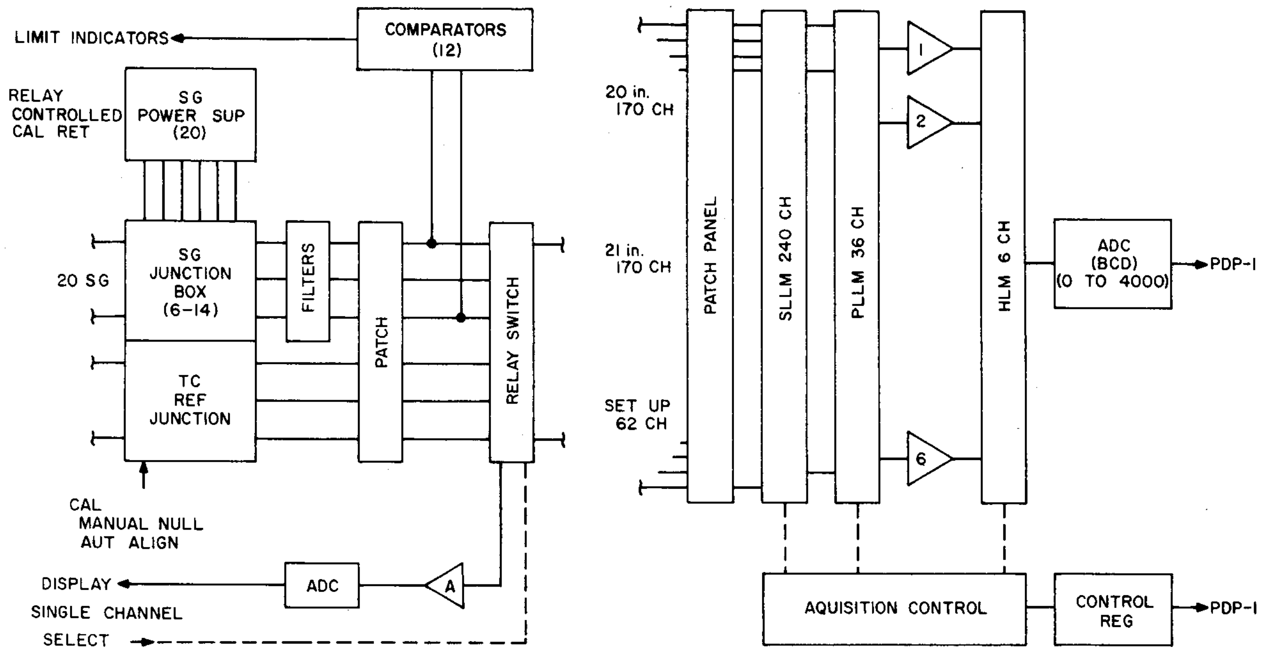


Fig. IV-5. Company E, analog system

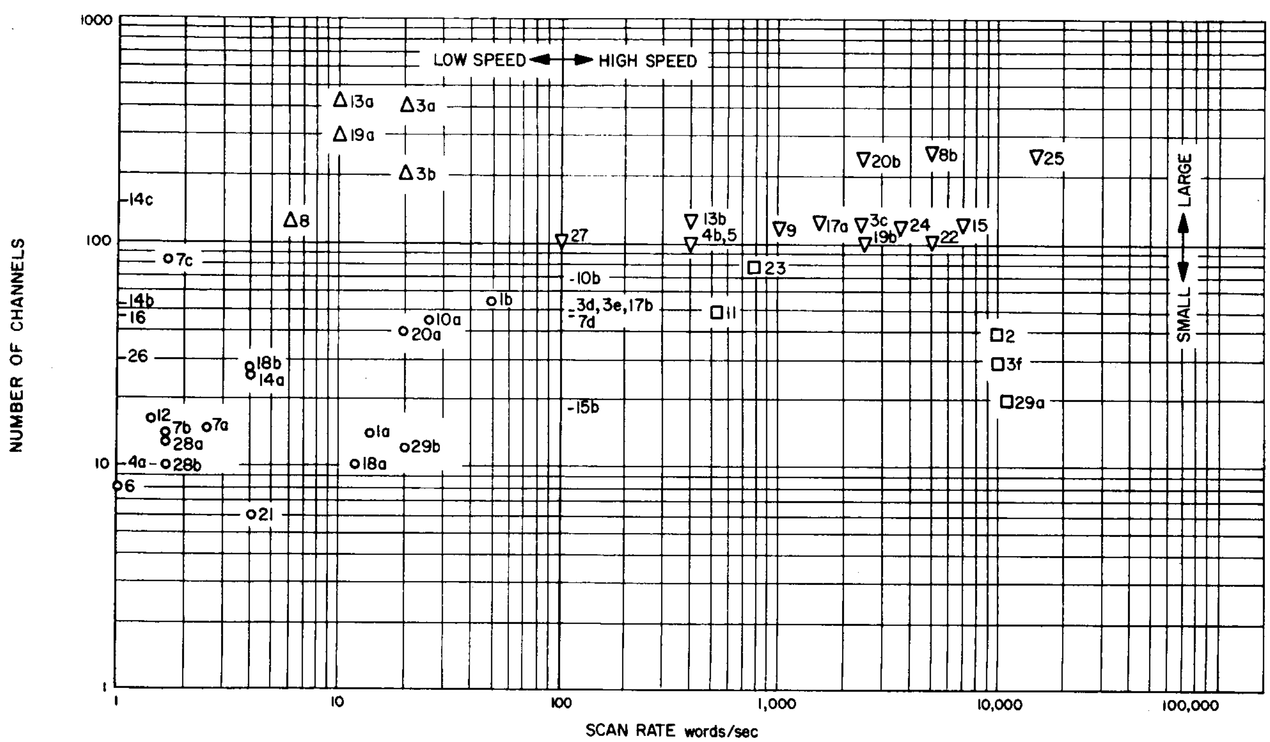


Fig. V-1. Speed-capacity spectrum of systems

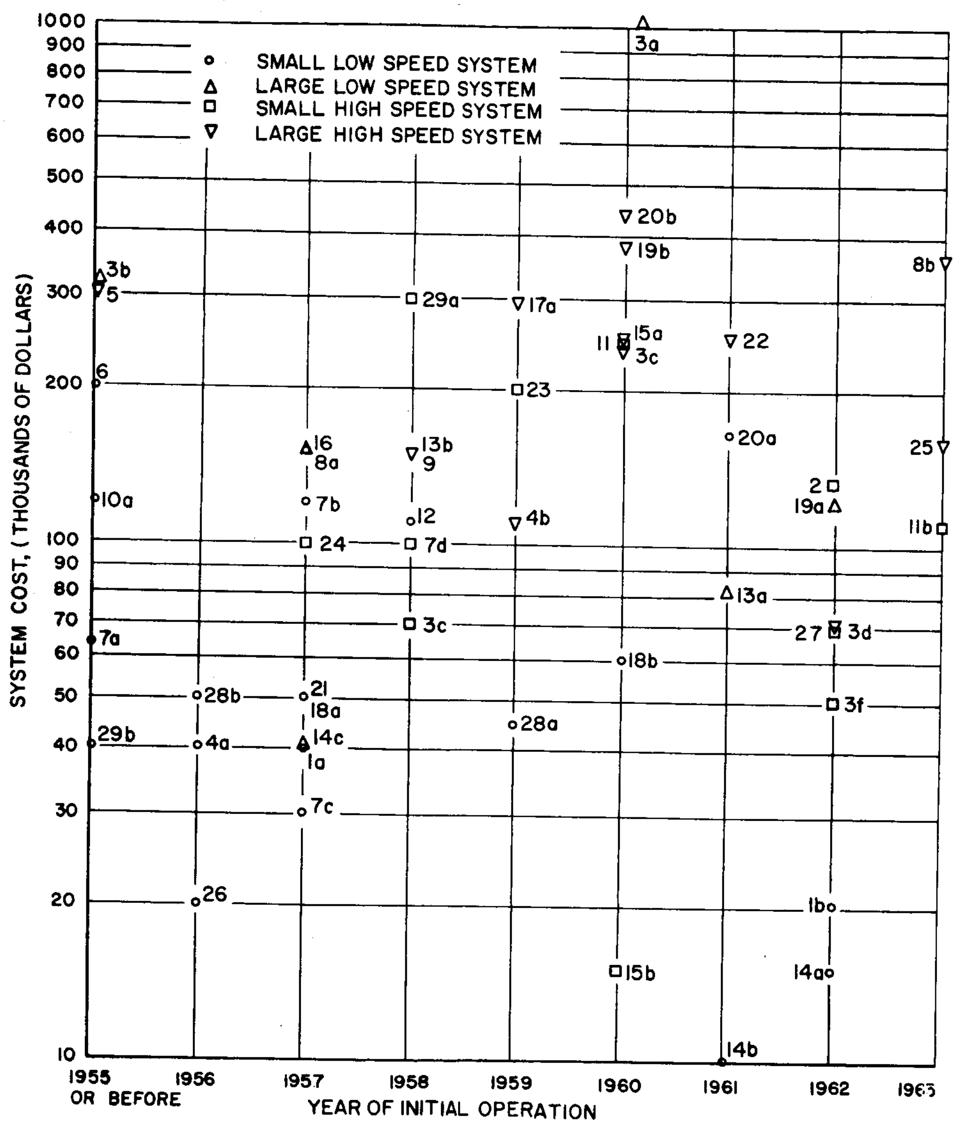


Fig. V-2. Age-cost spectrum of systems

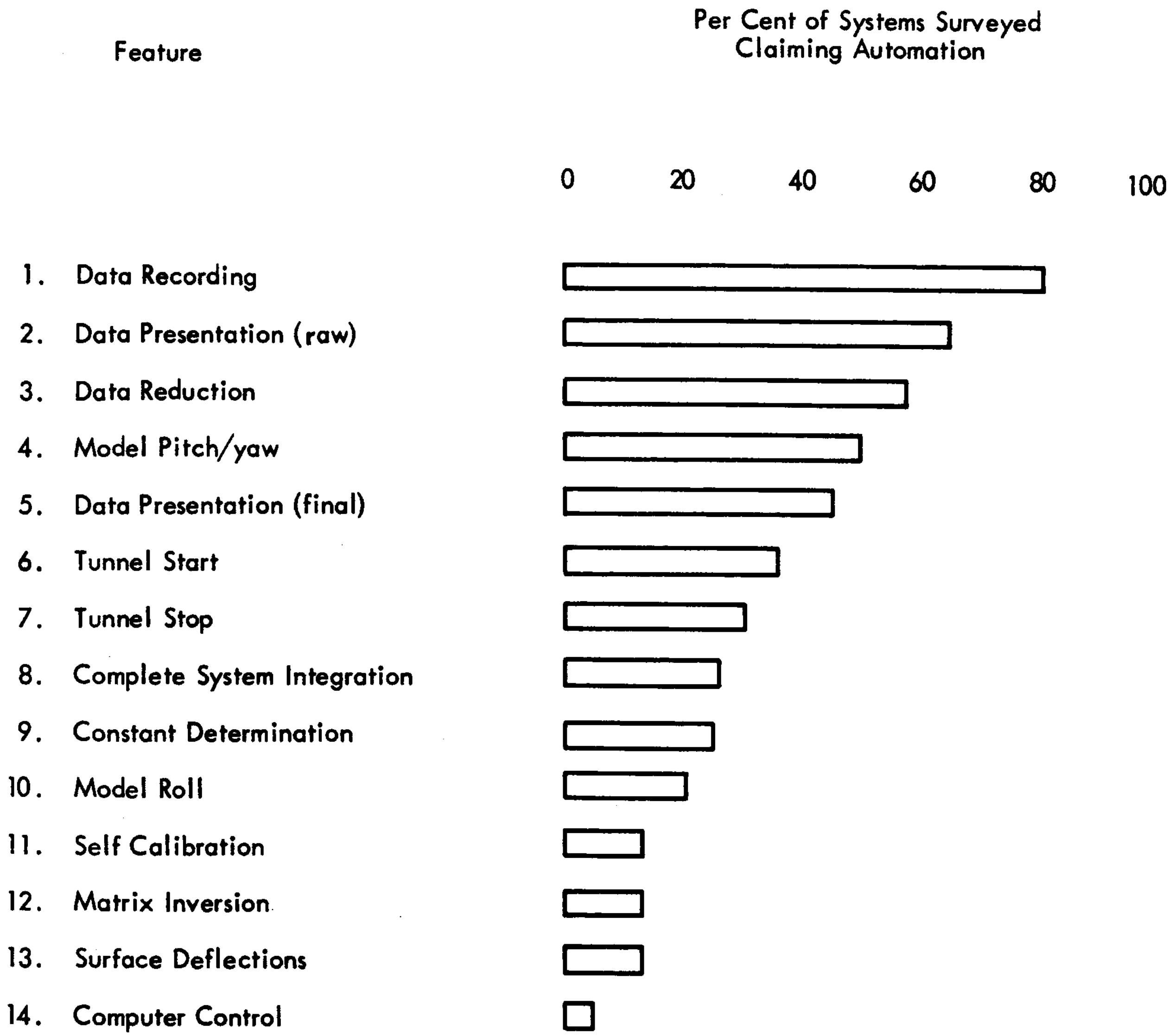


Fig. V-3. Degree of automation

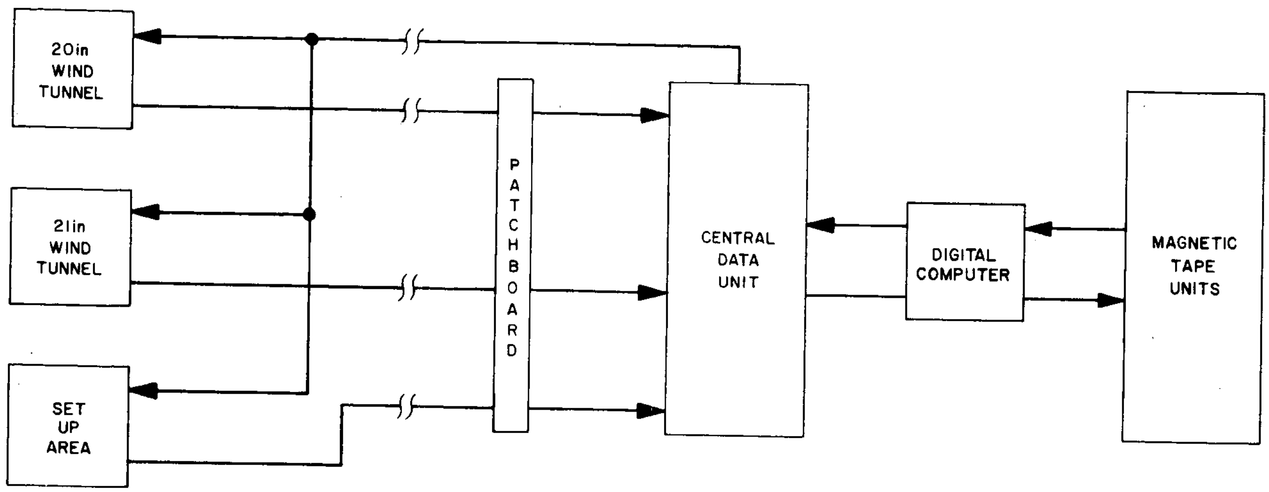


Fig. V-4. System block diagram

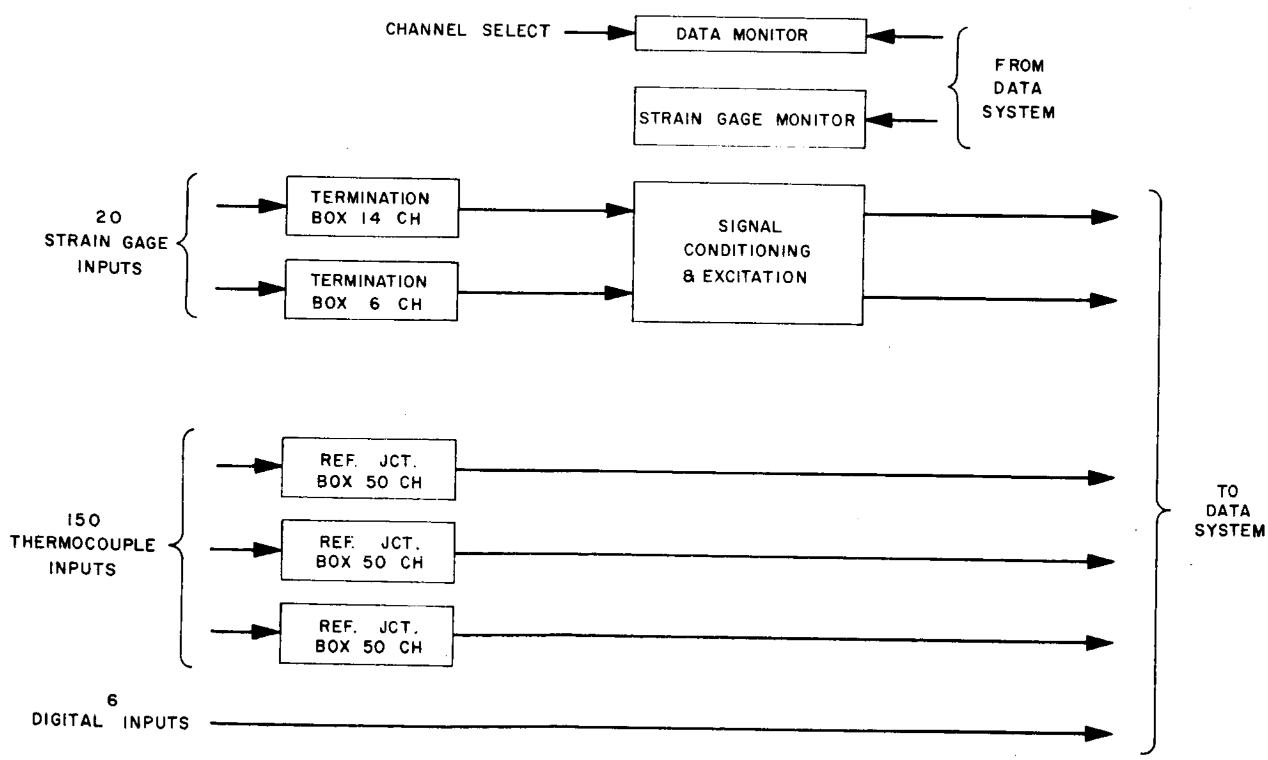


Fig. V-5. Test site subsystem

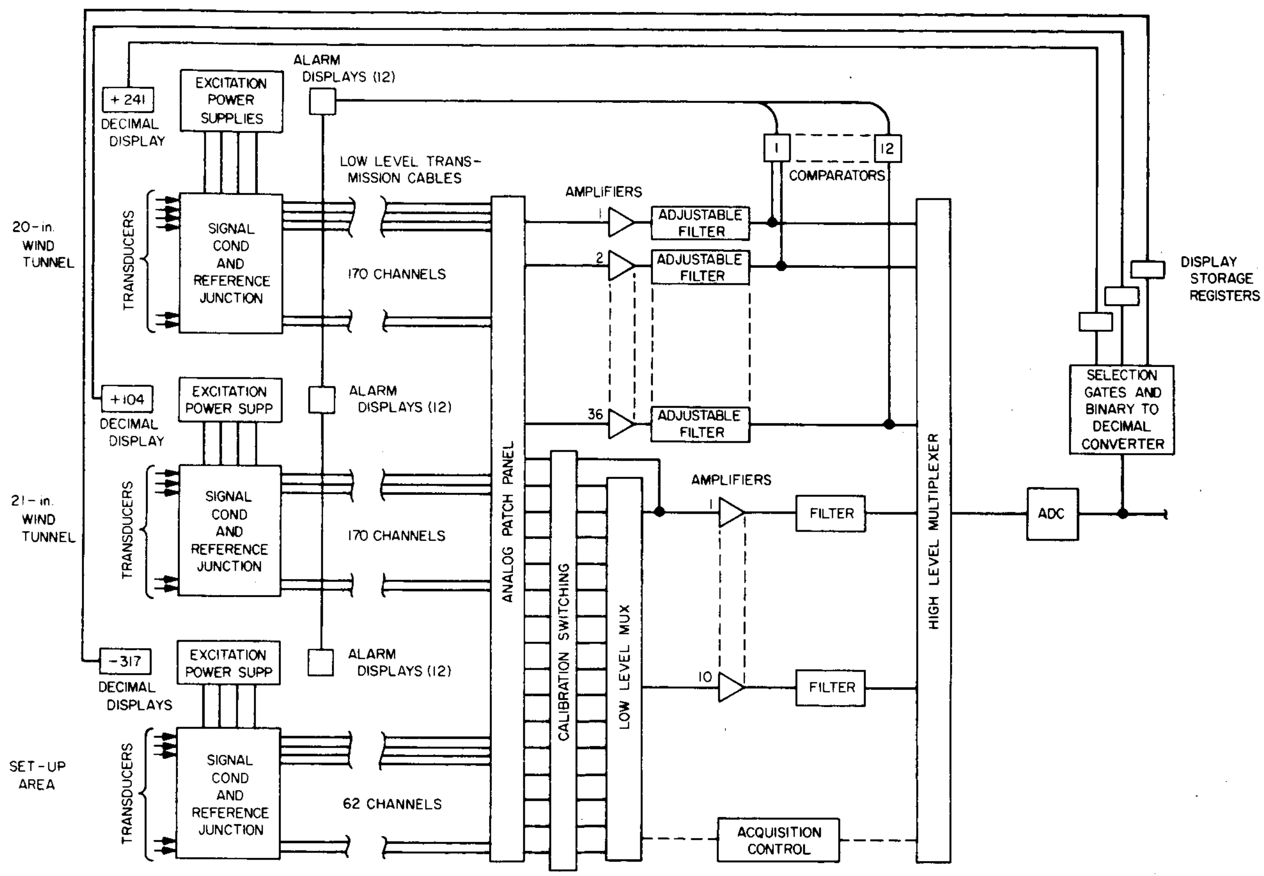


Fig. V-6. Analog signal flow path

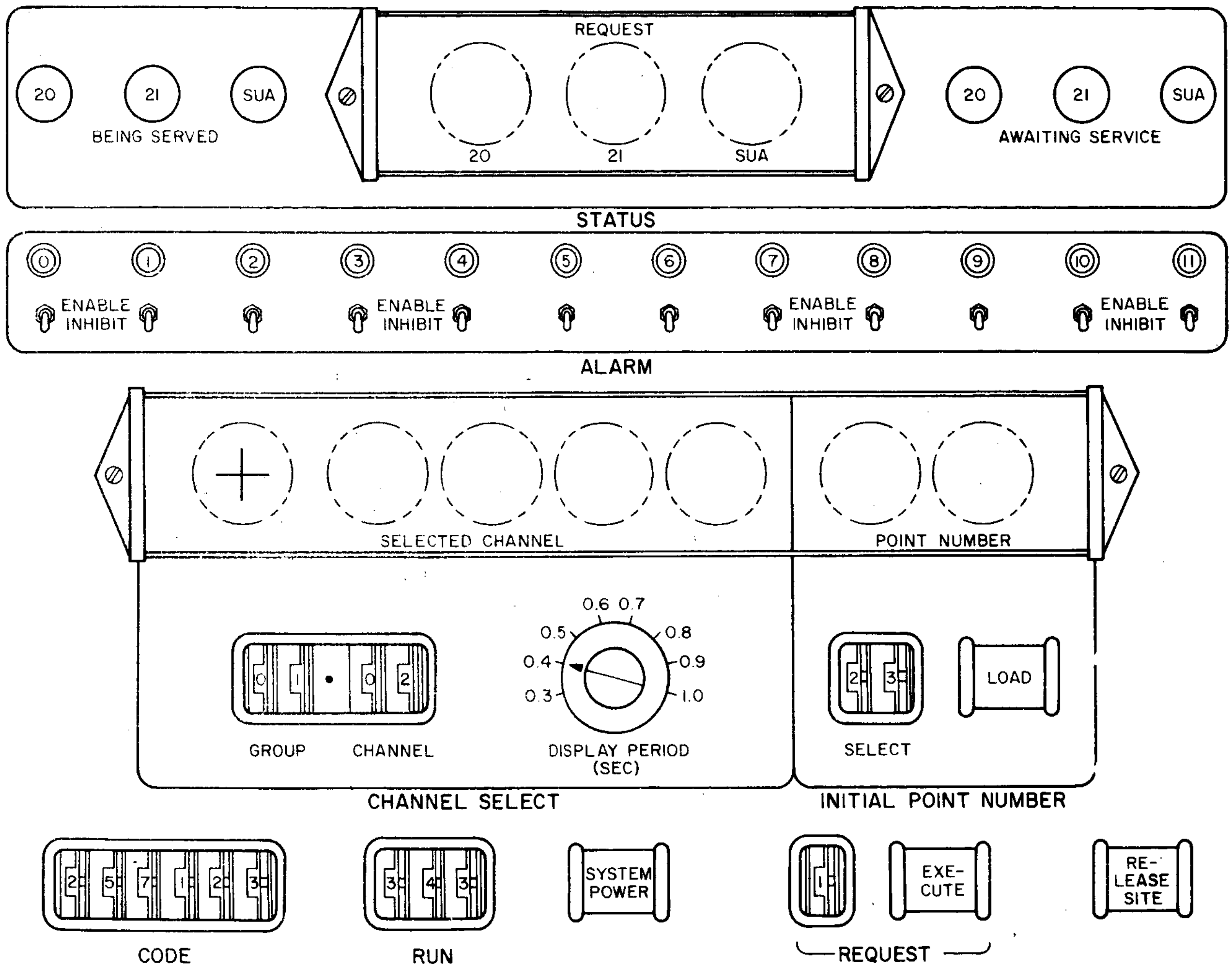
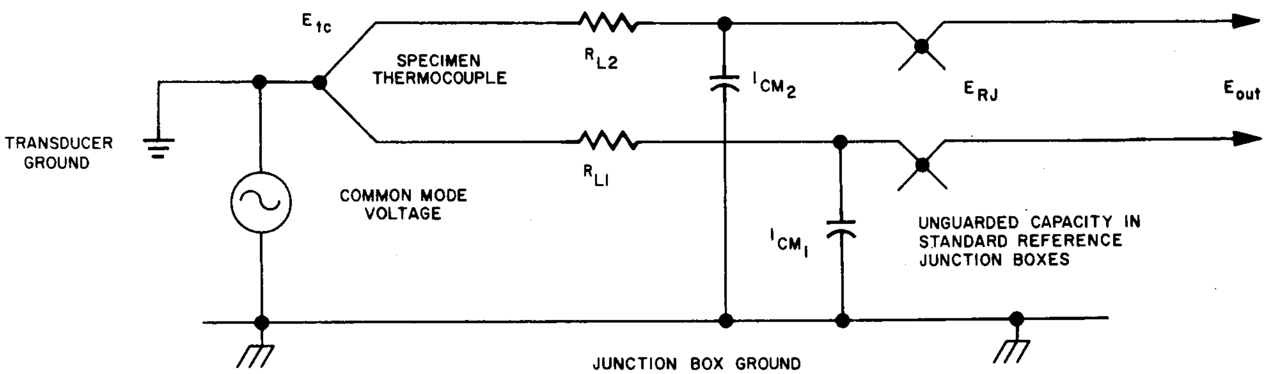


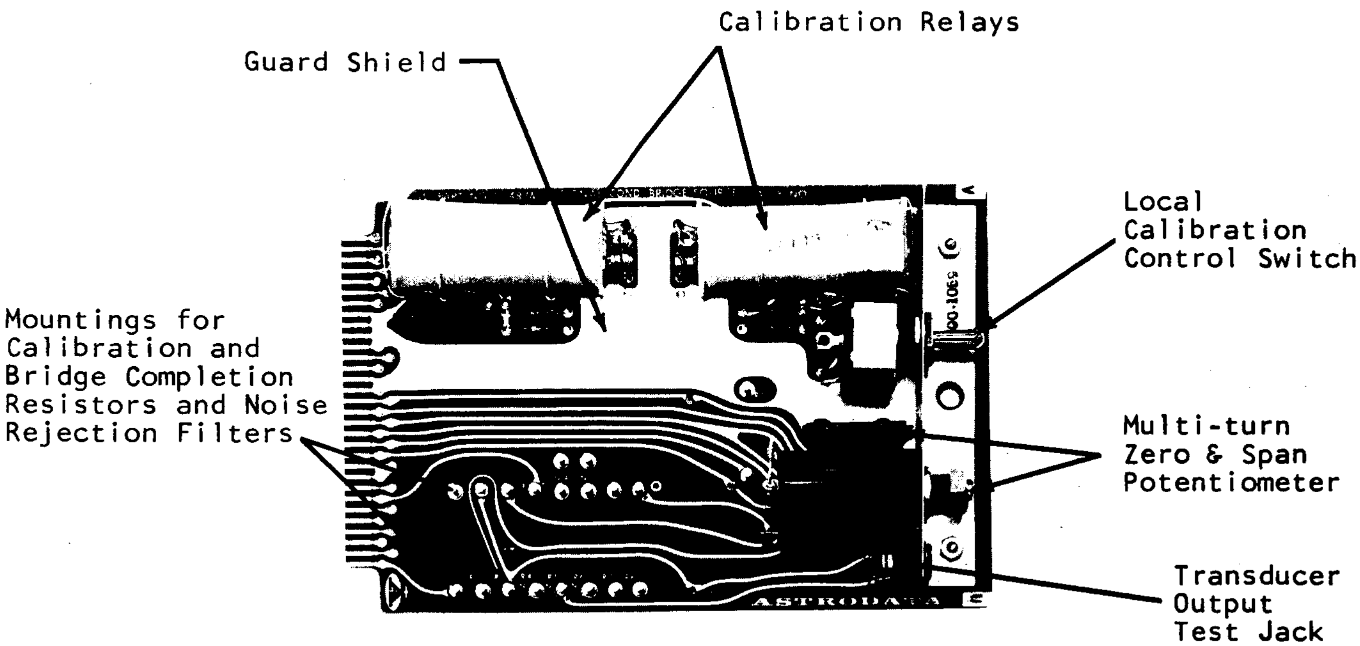
Fig. V-7. Control panel at wind tunnel sites



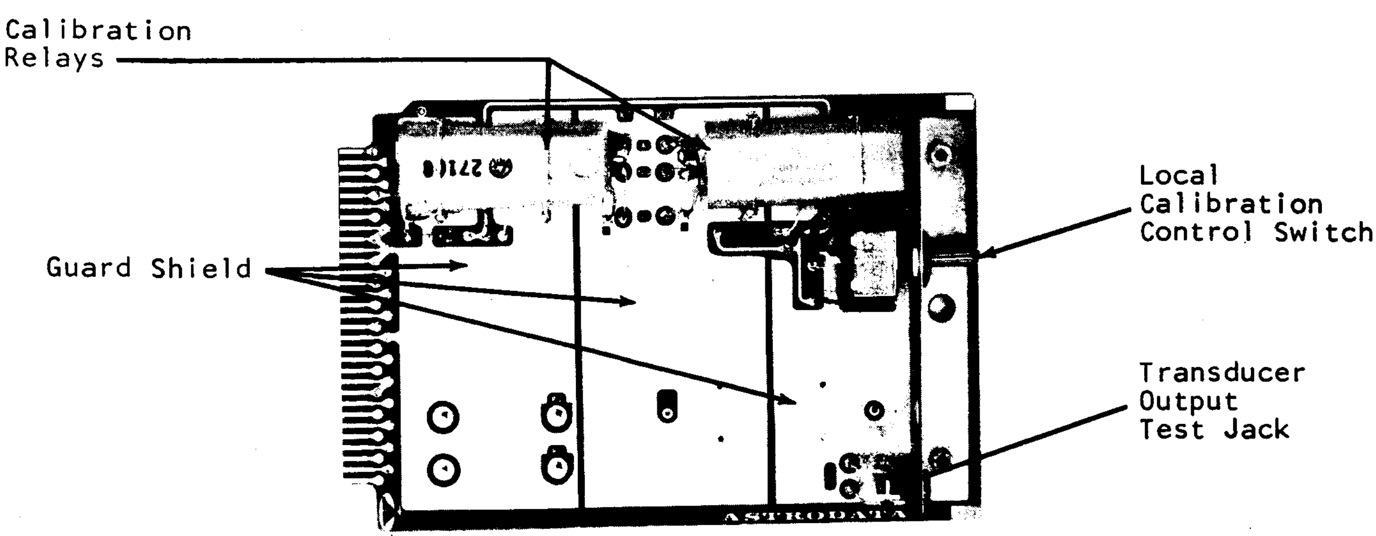
$$E_{OUT} = E_{TC} - E_{RJ} + I_{CM} (R_{L1} - R_{L2})$$

THE COMMON MODE CURRENTS FLOWING IN THE THERMOCOUPLE LEAD WIRES PRODUCE A DIFFERENTIAL ERROR SIGNAL IF LEAKAGE IS PRESENT.

Fig. V-8. Common mode interference caused by unguarded capacitance

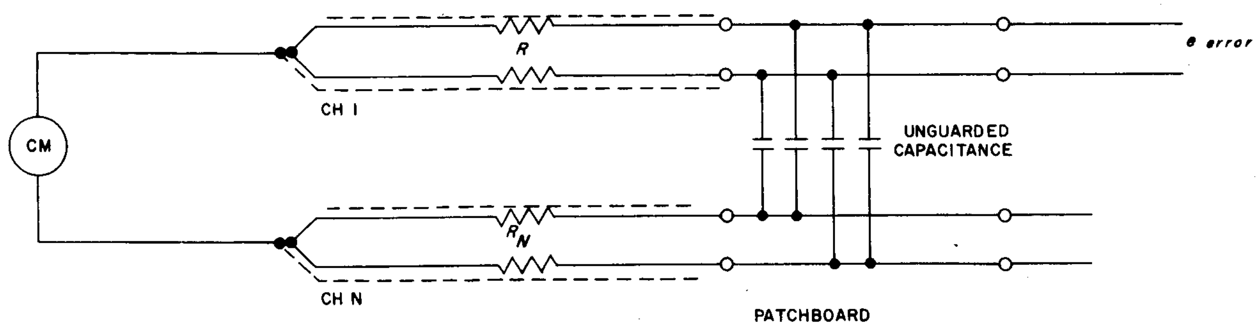


BRIDGE TYPE SIGNAL CONDITIONING MODULE



VOLTAGE OR THERMOCOUPLE TYPE SIGNAL CONDITIONING MODULE

Fig V-9 Universal signal conditioning modules



$$e_{error} = \frac{\text{COMMON MODE VOLTAGE}}{R + R_N + X_C} \times \Delta R$$

WHERE ΔR = DIFFERENCE IN INPUT LEAD RESISTANCE ON CHANNEL BEING MEASURED

R_N = RESISTANCE TO COMMON MODE SOURCE OF ALL OTHER CHANNELS

X_C = UNGUARDED CAPACITANCE OF PATCHBOARD AT COMMON MODE FREQUENCY

Fig. V-10. Error due to unguarded capacitance at patchboard

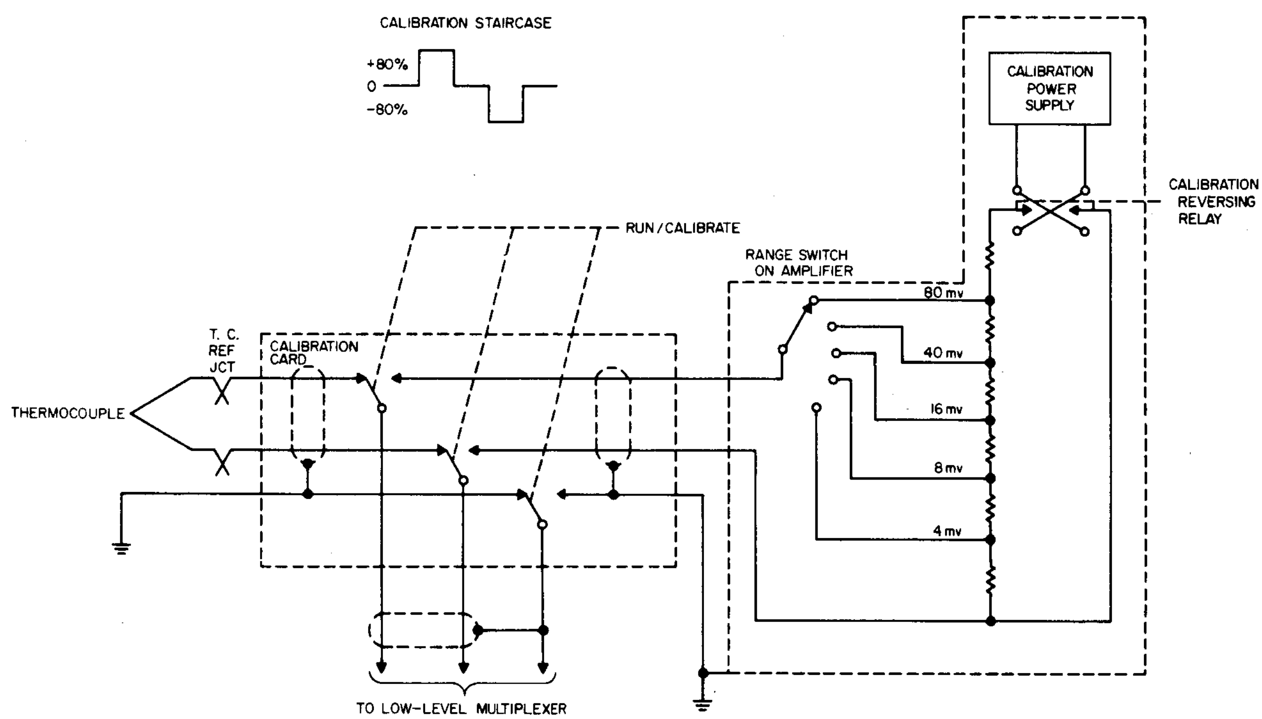


Fig. V-11. Voltage calibration (thermocouple inputs)

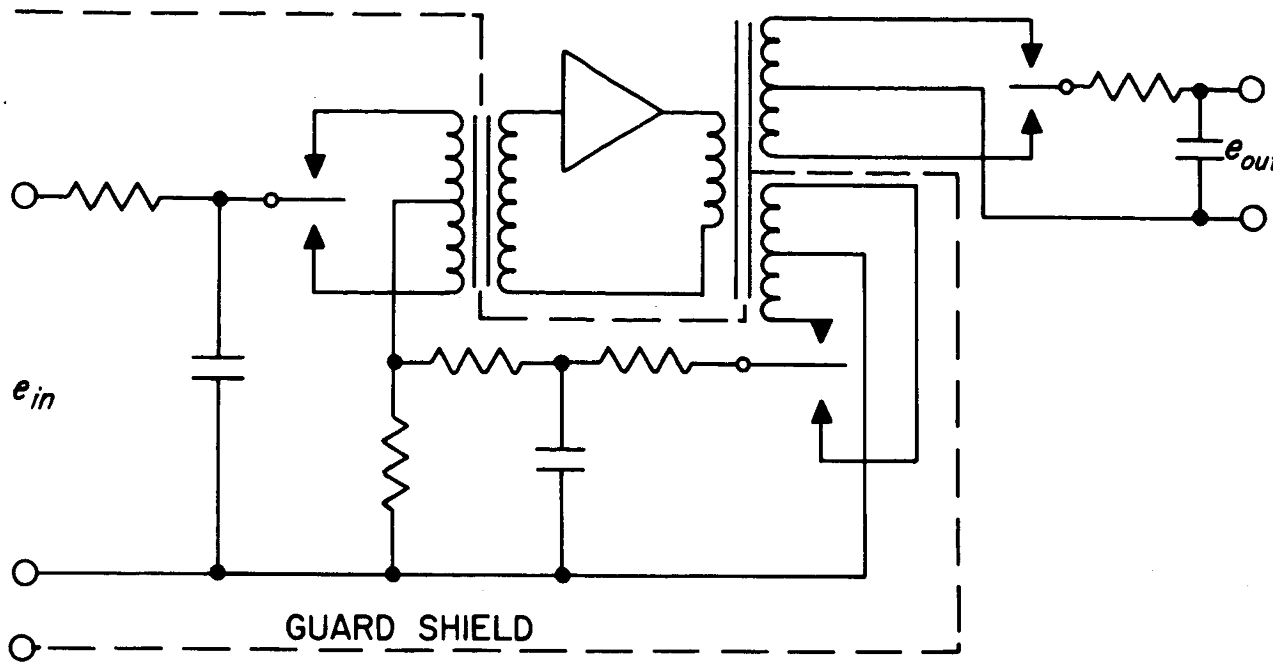


Fig. V-12A. Amplifier with input isolator

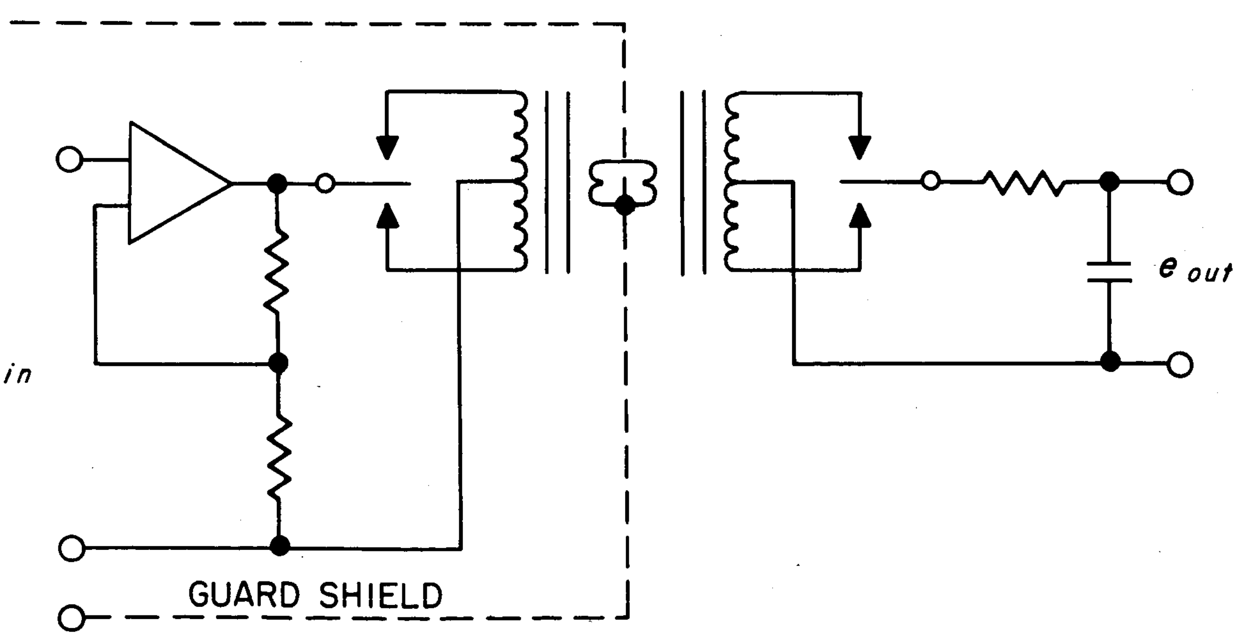


Fig. V-12B. Amplifier with output isolator

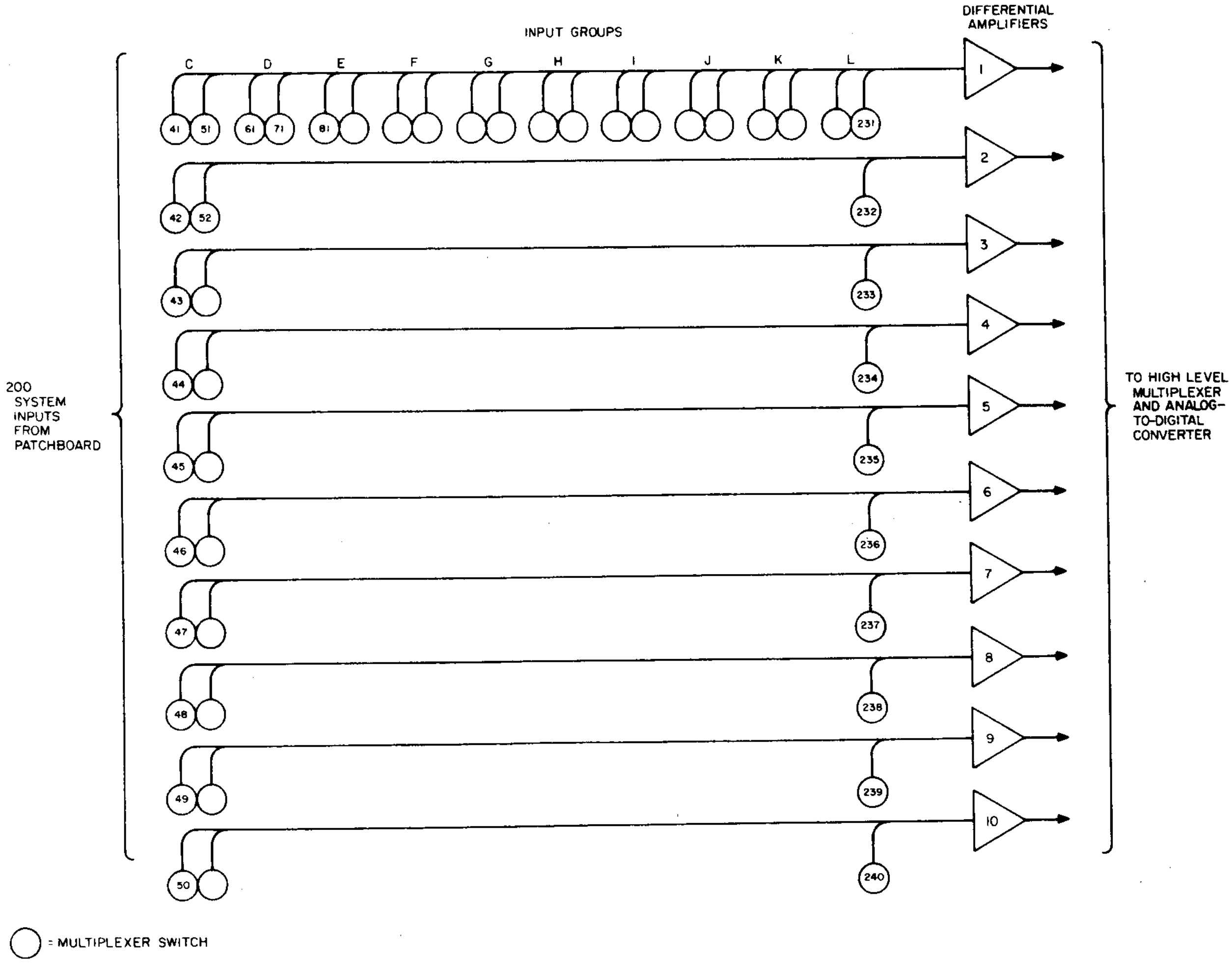


Fig. V-13. Low level multiplexer organization

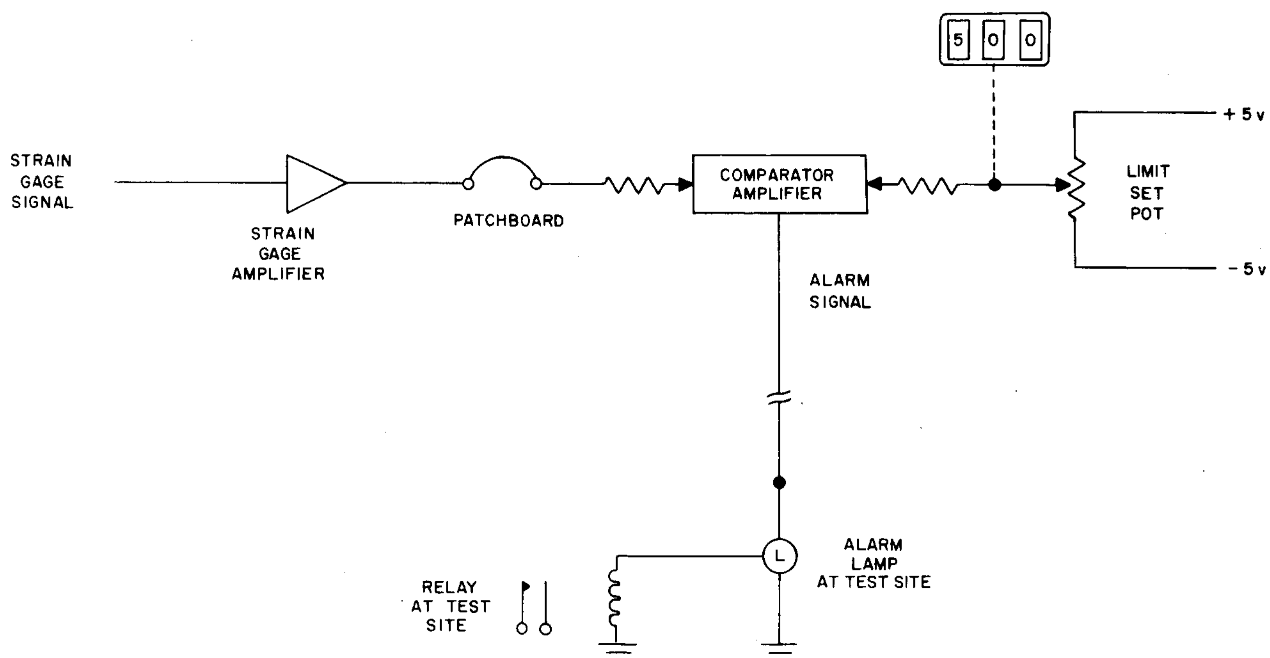


Fig. V-14. Strain gage monitor

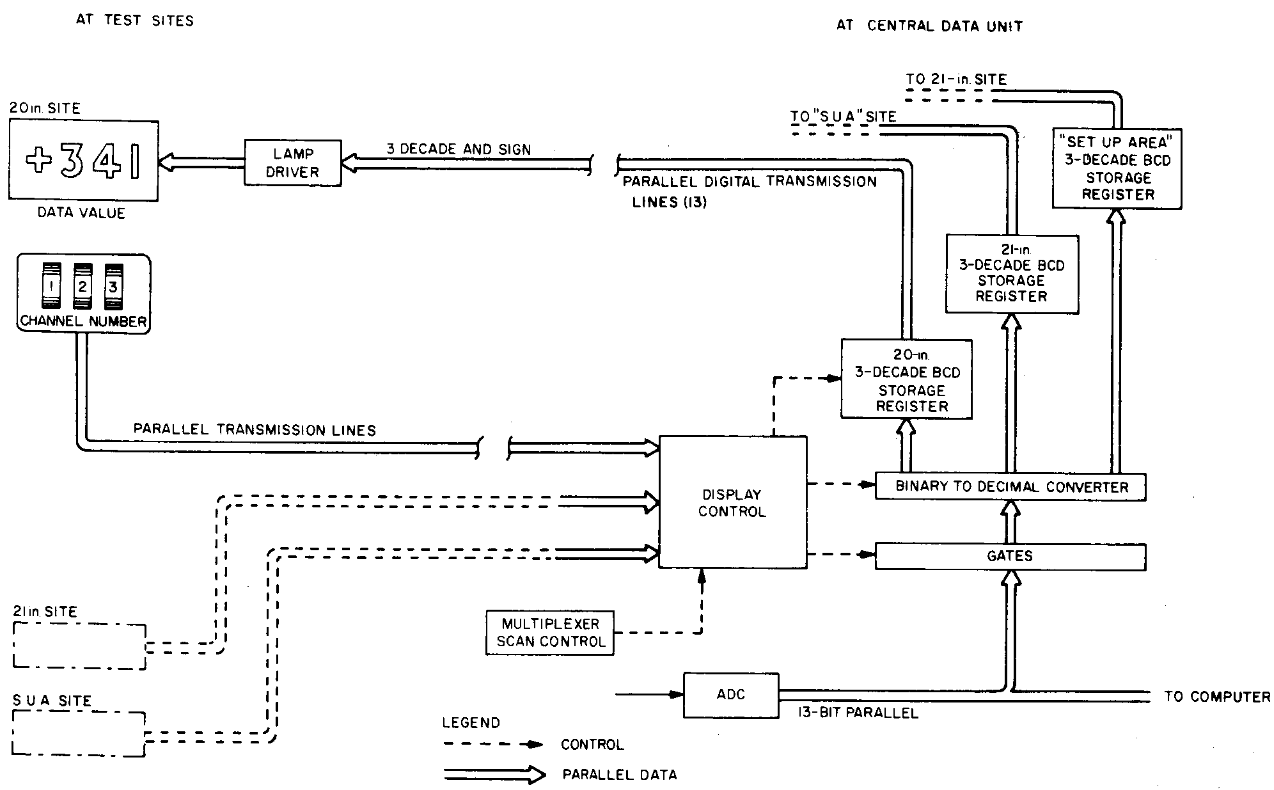


Fig. V-15. Data display system

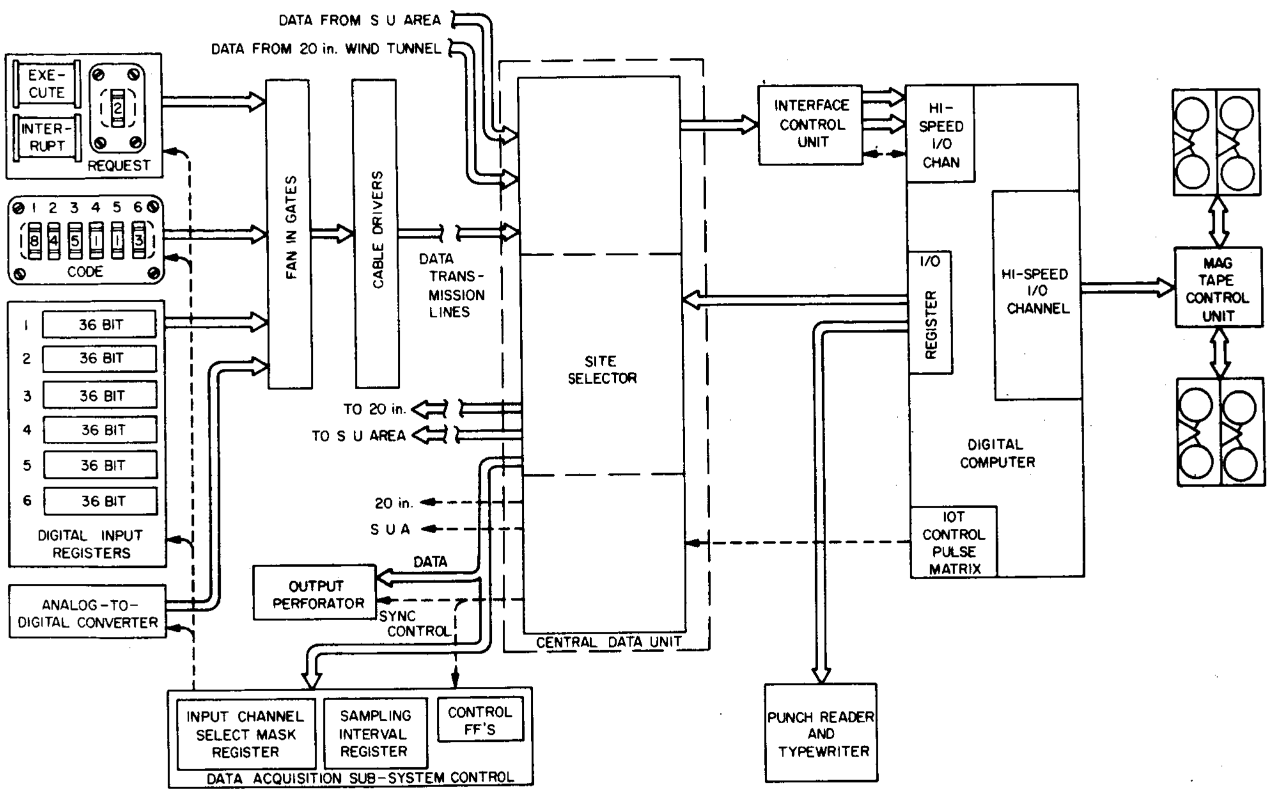


Fig. V-16. Computer interface

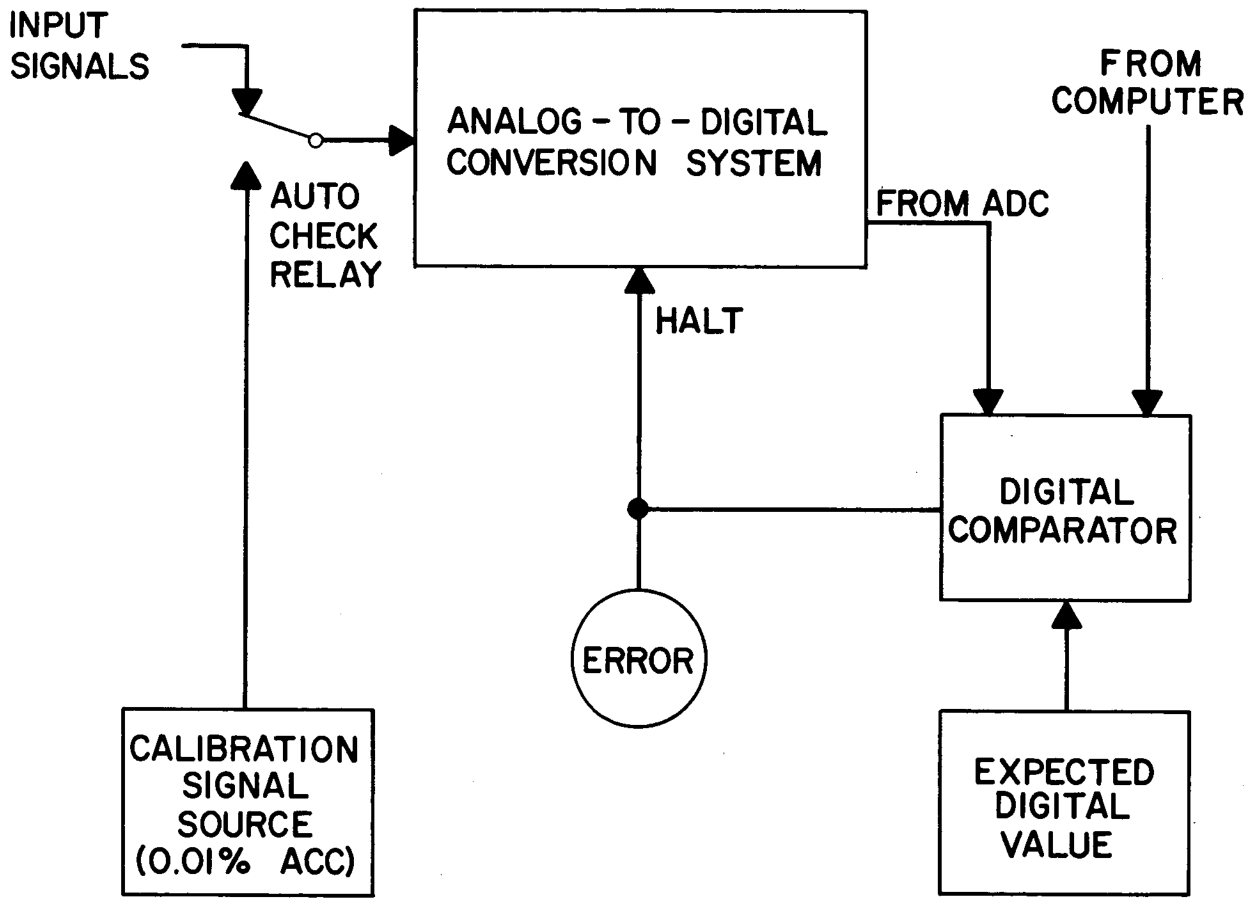


Fig. V-17. Automatic system-checker

Fig. V-18. Test site control panel

Fig. V-19. Central data unit

Fig. V-20. PDP-1 Computer

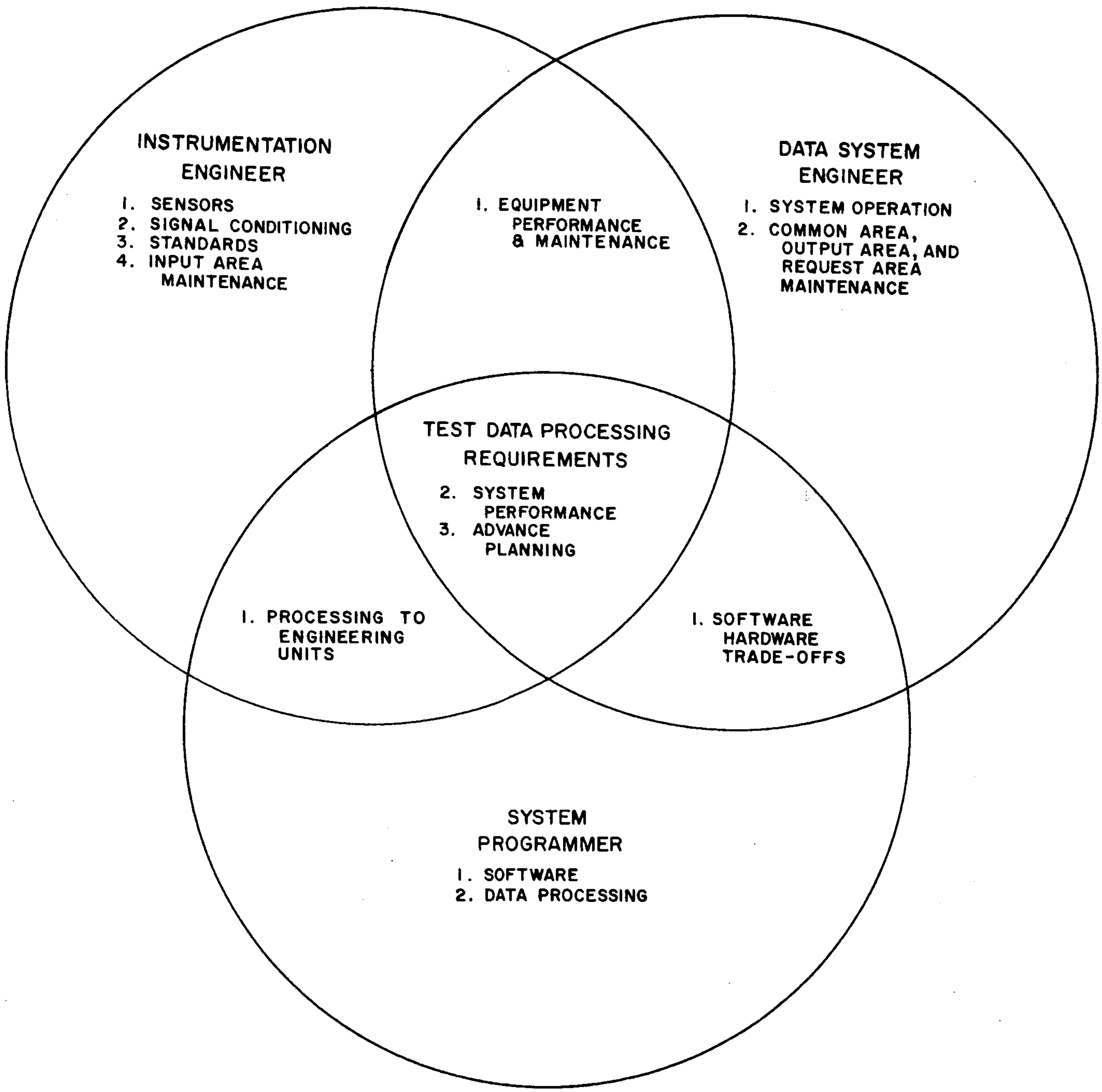


Fig. V-21. Data system team

APPENDIX A

Derivation of Figure III-1

To find the uncertainty in q for a given uncertainty in p_t as affected by the uncertainty in Mach number write

$$\frac{\frac{\partial q}{q}}{\frac{\partial p_t}{p_t}} = \frac{\frac{\partial q}{dM}}{\frac{\partial p_t}{dM}\left(\frac{q}{p_t}\right)_M}$$

$$q = \frac{\gamma}{2} PM^2$$

$$\frac{\partial q}{\partial M} = \gamma \; pM$$

$$p_t = p(1+ \frac{\gamma-1}{2} M^2) \; \frac{\gamma}{\gamma-1}$$

$$\frac{\partial p_t}{\partial M} = p \frac{\gamma}{\gamma-1} \; (1 + \frac{\gamma-1}{2} \; M^2) \; \frac{1}{\gamma-1} \; \left[(\gamma-1)M\right]$$

then

$$\frac{\frac{\partial q}{2}}{\frac{\partial p_t}{p_t}} = \frac{1 + \frac{\gamma-1}{2} M^2}{\frac{\gamma}{2} M^2}$$

To find the uncertainty in q for a given uncertainty in p as affected by the uncertainty in Mach number write

$$\frac{\frac{\partial q}{q}}{\frac{\partial p}{p}} = \frac{\frac{\partial q}{\partial M}}{\frac{\partial p}{M}} \; \frac{q}{p} \; M$$

$$q = \frac{\gamma}{2} \; p_t M^2 \; (1 + \frac{\gamma-1}{2} M^2)^{\frac{\gamma}{1-\gamma}}$$

$$\frac{\partial q}{\partial M} = \frac{\gamma}{2} \, p_t \; \left[2M(1 + \frac{\gamma-1}{2} M^2)^{\frac{\gamma}{1-\gamma}} - \gamma M^3 \; (1 + \frac{\gamma-1}{2} M^2)^{\frac{2\gamma-1}{1-\gamma}}\right]$$

$$p = p_t \left(1 + \frac{\gamma-1}{2} M^2\right)^{\frac{\gamma}{1-\gamma}}$$

$$\frac{\partial p}{\partial M} = -p_t \gamma M \left(1 + \frac{\gamma-1}{2} M^2\right)^{\frac{2\gamma-1}{1-\gamma}}$$

then

$$\frac{\frac{\partial q}{q}}{\frac{\partial p}{p}} = 1 - \frac{1 + \frac{\gamma-1}{2} M^2}{\frac{\gamma}{2} M^2}$$

To find the uncertainty in q for a given uncertainty in p_t' as affected by the uncertainty in Mach number write

$$\frac{\frac{\partial q}{q}}{\frac{\partial p_t'}{p_t'}} = \frac{\frac{\partial q}{\partial M}}{\frac{\partial p_t'}{\partial M} \left(\frac{q}{p_t'}\right)_M}$$

$$q = \frac{\gamma}{2} pM^2$$

$$\frac{\partial q}{\partial M} = \gamma pM$$

$$p_t' = p\left(\frac{\gamma+1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} \left(\frac{\gamma+1}{2\gamma M^2-\gamma+1}\right)^{\frac{1}{\gamma-1}}$$

$$\frac{\partial p_t'}{\partial M} = \gamma \frac{\gamma+1}{\gamma-1} PM \left\{\left[\frac{(\gamma+1)^2 M^2}{2(2\gamma M^2-\gamma+1)}\right]^{\frac{1}{\gamma-1}} - 4\frac{\left[\frac{M^2}{2}(2\gamma M^2-\gamma+1)\right]^{\frac{\gamma}{\gamma-1}}}{(2\gamma M^2-\gamma+1)^2}\right\}$$

$$\frac{\frac{\partial q}{q}}{\frac{\partial p_t'}{p_t'}} = \frac{2(\gamma-1)\left(\frac{\gamma+1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} \left(\frac{\gamma+1}{2\gamma M^2-\gamma+1}\right)^{\frac{1}{\gamma-1}}}{(\gamma+1)M^2 \left\{\left[\frac{(\gamma+1)^2 M^2}{2(2M^2-\gamma+1)}\right]^{\frac{1}{\gamma-1}} - 4\frac{\left[\frac{M^2}{2}(2M^2-\gamma+1)\right]^{\frac{\gamma}{\gamma-1}}}{(2M^2-\gamma+1)^2}\right\}}$$

JPL SPEC 30701 B

DATE: 30 August 1962

ENGINEER: Robert E Martin
Robert Martin

RELEASE: L. S. Doubt
L. S. Doubt

SUPERSEDES:

JPL SPEC. NO. 30701 A

DATED: 21 May 1962

DESIGN SPECIFICATION
WIND TUNNEL FACILITY
DATA SYSTEM

REVISED AND REWRITTEN

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

1. SCOPE

1.1 Scope. This specification covers the design requirements and functions for a Data System for the wind tunnel complex, capable of acquiring digital data from all tunnel activities and processing data for standard type test.

1.2 Functional description. The Data System shall be capable of:

a. Logging of data from three testing sites, the 20-inch tunnel, 21-inch tunnel, and set-up area in Building 67.

b. Displaying in the testing area sufficient data to control the testing.

c. Processing the quasi-steady state data to final coefficients.

d. Logging data in a form acceptable to the IBM 7090 computer for further processing.

e. Providing punched paper tape acceptable to the present raw and final data display system.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification:

SPECIFICATIONS

Jet Propulsion Laboratory

20014	General Specification, Soldering Process
20016	General Specification, Workmanship Requirements for Electronic Equipment
20061	JPL Preferred Parts List, Reliable Electronic Components

DRAWINGS

Jet Propulsion Laboratory

6-9133 188	Data System Space Allocation

3. REQUIREMENTS

3.1 Precedence. In case of conflict between the requirements of this specification and any referenced document herein, the following requirements shall govern. Any conflict shall promptly be referred in writing to the JPL cognizant engineer and the JPL procurement division for interpretation and clarification.

3.2 Request for deviation. Any change from the requirements of this specification, or applicable documents listed herein shall be considered a design change or deviation. Request for deviation shall be submitted in writing to JPL for consideration and consent.

3.3 Materials, parts and processes. Materials, parts and processes used in the design, fabrication, and assembly of the items covered by this specification shall conform to the applicable documents specified herein. The contractor's selection shall ensure the highest uniform quality and condition of items; such selection shall be subject to the approval of JPL.

3.3.1 Interchangeability. All parts having the same part number shall be directly and completely interchangeable, with respect to installation and function.

3.4 Design.

3.4.1 Design approval. The contractor shall submit final design drawings, sketches, schematics, etc., for the JPL cognizant engineer's approval, prior to fabrication; any design approval or purported consent by JPL personnel shall in no way waive or release the contractor from any performance requirements, specifications, or characteristics as set forth in this specification.

3.4.2 General. The Data System shall consist of the following units:

a. Data acquisition subsystem.
   1) Digital input data (per test site).
      Run-point word
      Code word
      Six 36-bit channels
   2) Analog input data.
      Strain gage channels
      Thermocouple channels
   3) Signal patching, conditioning, and monitoring equipment.
   4) Data acquisition subsystem control.

b. Data processing subsystem.
   1) Computer system (government furnished - JPL) DEC PDP-1. Basic machine with control console typewriter I/O and paper tape I/O and following optional equipment:

(a) Automatic multiply and divide, Type 10.
(b) 8096 word memory, Type 15 memory switching.
(c) Magnetic tape control unit, Type 52.
(d) Three magnetic tape handlers, Type 50. (Potter 602 II, 15-kc, IBM compatible).
(e) High speed input-output channel, Type 23.
(f) Sixteen-channel sequence break system, Type 20.

2) JPL-supplied software:
(a) Modified "frap" symbolic assembly program.
(b) Executive control program.
(c) Program debugging aids.

3) Contractor-supplied software. Contractor-supplied software is to be submitted in symbolic form compatible with JPL-supplied frap assembly program.
(a) Data acquisition subsystem control routine.
(1) Acquisition mode and rate.
(2) Sampling and recording control.
(b) Data system input logging routine(s).
(c) Data system output logging routine(s).
(d) Data system calibration routine.
(e) Data system performance evaluation routine(s).

4) Computer system integration equipment.
(a) Input assembly register(s).
(b) Request register(s).
(c) Data acquisition subsystem control register(s).
(d) Output paper tape punches (one per testing site).

c. Equipment areas.

1) Input area (one per testing site).
(a) Input junction boxes.
(b) Thermocouple reference boxes.
(c) Signal conditioning units.

2) Test control area (one per testing site).
(a) Run-point word, code word, request switches.
(b) Single channel select switch and display.
(c) Alarm display.
(d) Status lights.

3) Test output area (one per testing site).
   (a) Computer output punch.
   (b) Raw data display system (government furnished-JPL).
4) Common area.
   (a) Computer and magnetic tape handlers.
   (b) Amplifiers.
   (c) Multiplexer.
   (d) Limit-alarm units.
   (e) Performance analyzer.
   (f) Calibration voltage source

3.4.3 Design objectives. The system shall be designed for optimum operation in accordance with the following priority list.

a. Reliability. Reliability is of prime importance and can be achieved only by careful and thorough analysis, design, development, fabrication and testing. A minimum down time during scheduled tunnel operating time is desired.
b. Accuracy.
c. Flexibility. The nature of wind tunnel testing is such that an accurate forecast of future data system needs is not possible. Therefore the ability to tailor the system to changing needs is highly desirable.
   1) Additional testing sites.
   2) Scan sequence and length.
   3) Sampling rate.
   4) Channel capacity.

3.5 Operational characteristics.

3.5.1 Requests are made directly to the computer.

a. Programmable priority.
b. Automatic execution of highest priority request.
c. Completion of request before inspection for next request except for end logging request.
d. Requests.

1) Run change. New run number and constant code.
2) Log data. Eight separate requests required (defined in computer program).
3) End logging.

3.5.2 Data scan format. The data scan format shall be under computer control with the strain gage channels addressable in blocks of ten and the thermocouple channels addressable in blocks of twenty. The digital channels of the site being serviced will be interlaced with the first block of analog channels recorded.

a. Run-point word. Five digit number set by hand switches. The first three digits are for run number and can be set from 000 to 399. The last two digits are for point number which shall increase automatically by one count at the beginning of every logging request.
b. Code word. Six digits set manually by operator at test control area and scanned on run change request.

3.5.3 Logging modes.

a. Quasi-steady state.
   1) One to sixteen samples per channel (in increments of the power of two) for arithmetic averaging by computer.
   2) One to 10 samples per second per channel.
   3) Twelve programmable channels transmitted to the computer output punch in the test output area.
b. Continuous. Basic rate of 2000 samples per second. A maximum rate of 5000 samples per second available. Sampling rate shall be under computer control. Logging terminated by stop request.
c. Periodic. The scan rate shall be under computer control and variable from 100 to 0.1 scans per second.
d. External timing. Upon receipt of the external timing pulse, the acquisition subsystem shall reset to a computer-selected logging scan format and the system log one scan. Upon completion of the logging the acquisition subsystem resets to the monitor scan format. Upon completion of a computer defined number of scans, the external timing mode log request is completed.

e. Logging signal. A voltage level type signal for external tunnel control is required during logging.

3.5.4 Single channel display system. Any analog channel may be selected for display in digital form at the test control area. The set-up area select and display system shall be duplicated in the common area. The digital display shall be four-digit decimal and the equivalent of the binary coded output of the systems analog-to-digital converter.

3.5.5 Monitor-alarm system. Twelve adjustable bipolar analog limit alarm units shall be available for the continuous monitoring of manually selected strain-gage channels. An alarm (lamp) shall be indicated at a selected site (20 or 21 inch tunnels) when the voltage exceeds a preset range.

3.5.6 System calibration. A calibration method shall be provided which is under computer control so that an automatic calibration of the system can be performed.

3.5.7 System status displays. When a request is made at a site, the request number is displayed at the other sites until the request is completed, at which time the indicator is turned off. An indicator at each site shall indicate when and which site is logging data.

3.6 Performance characteristics.

3.6.1 Digital input channels.

a. Six channels required for each test site, each consisting of 36 bits.

b. The channels shall be capable of accepting inputs consisting of contact closures and logical levels of 0 and -6 volts.

c. The digital channels shall be composed of logic elements capable of 500 kc operation.

3.6.2 Analog inputs.

a. Strain gage channels (including power supplies).

1) Amount and location of equipment.

Test Site	Amplifiers	Conditioning Units	Rack and Wiring Capacity
20-inch tunnel	0	14	20
21-inch tunnel	0	14	20
Set-up area	0	8	12
Common area	25	0	40

2) Full scale input ranges available. ±2.5, ±5, ±10, ±30, and ±50 mv.

Note: Channels shall be in blocks of up to ten.

3) Isolation. Provision shall be made for isolated inputs on all channels (guard shielded type with 3-wire switching), allowing each channel its own ground reference.

4) Filters. Lowpass filters, cut-off frequencies (3 db down) with at least 12 db/oct cutoff for 2.5, 5, 20, and 100 cps.

5) Rejection. Common-mode rejection shall be greater than 10^6:1.

6) Cross talk. Cross talk between channels shall be less than 0.01 percent.

7) Accuracy. Analog input voltage to final digital value (including power supplies).

(a) Short term. 8 hours, after a half hour warm-up.

	Error (% FS) (3σ) Filter cutoff frequency (cps)			
Full Scale Voltage	2.5	5	20	100
±2.5 mv	.11	.11	.15	.3
+5 mv	.10	.10	.13	.2
±10 mv	.10	.10	.11	.15
±30 mv	.10	.10	.10	.12
±50 mv	.10	.10	.10	.10

(b) Long term. one week (continuous).

Full Scale Voltage	Error (% FS) (3σ)
±2.5 mv	.3
±5 mv	.2
±10 mv	.15
±30 mv	.10
+50 mv	.10

(c) Repeatability (one hour).

Full Scale Voltage	Error (% FS) (3σ) Filter cutoff frequency 2.5	5	20	100
±2.5 mv	.05	.06	.08	.16
±5 mv	.05	.05	.06	.10
±10 mv	.05	.05	.05	.07
±30 mv	.05	.05	.05	.05
+50 mv	.05	.05	.05	.05

8) Power supplies. Voltage shall be variable from 1 to 12 volts with sufficient capacity and regulation for 50, 120 and 350-ohm 2 and 4-arm bridges.

9) Calibration and balance equipment. Each strain-gage bridge shall be manually balanced and manually scaled by monitoring the gage output and adjusting the excitation voltage when a known resistance is inserted in parallel with various legs of the bridges. The parameter equivalent value of the known resistor shall be the same (±.02 percent) for all test sites, i.e., the equivalent value of a resistor as determined by a primary calibration in the set-up area shall be the same when used in a tunnel area. Jacks shall be provided on each channel to conveniently monitor the gage output signal and the strain gage excitation voltage.

b. Thermocouple channels (including reference junctions and calibration voltages).

1) Amount and location of equipment.

Test Site	Reference Junction Boxes	Wiring Capacity
20-inch tunnel	2	150
21-inch tunnel	2	150
Set-up area	1	50
Common area	0	200

2) Full scale input range ±5, ±10, ±20, and ±50 mv. Channels may be in blocks of up to 20.
3) Provisions shall be made for isolated inputs on all channels (guard shielded type with 3-wire switching) allowing each channel its own ground reference.
4) Common-mode rejection. Shall be greater than 10^6:1.
5) Cross talk between channels. Shall be less than 0.01 percent.
6) Accuracy. Analog input voltage to final digital value and including reference junction and calibration voltages.

(a) Short terms. 8 hours, after a half hour warm-up.

Full Scale Voltage	Error (% FS) (3σ)
+5 mv	.38
±10 mv	.22
±20 mv	.15
±50 mv	.10

(b) Long term. One week (continuous).

Full Scale Voltage	Error (% FS) (3σ)
±5 mv	.5
±10 mv	.3
±20 mv	.2
±50 mv	.2

(c) Repeatability (1 hour).

Full Scale Voltage	Error (% FS) (3σ) 2 KC Sampling Rate	Error (% FS) (3σ) 5 KC Sampling Rate
±5 mv	.20	.30
±10 mv	.12	.15
±20 mv	.06	.10
±50 mv	.05	.07

7) Reference junctions. Copper-constantan and/or chromel-alumel and/or chromel-constantan and/or iron-constantan and/or copper-copper controlled at a constant known temperature between 32°F and 200°F.

8) Calibration equipment for the thermocouple channels shall be provided (zero voltage reference as well as a signal of approximately 80 percent of full scale of the scale used).

c. Signal patching, conditioning and monitoring of strain-gage channels.

1) Termination box (near test area).

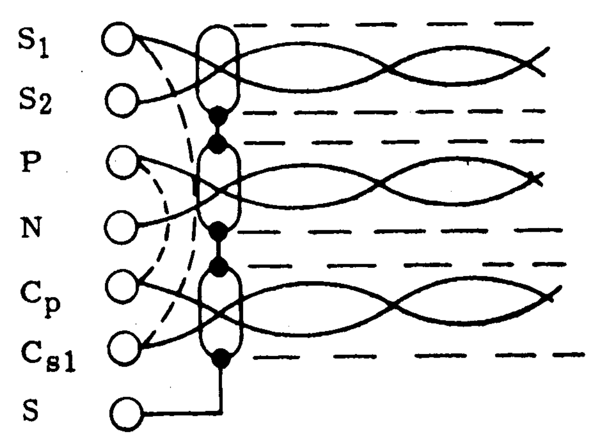
(a) The box shall be of a type with a hinged cover, recessed connection panel and large bushings in the bottom for external wiring entry (from transducers).

(b) The box shall contain:

Test site	Channels	Cable length
20	14	20 (?)
21	14	20 (?)
Set-up	12	10 (?)

(c) Input terminals (USECO or equivalent) for soldering; mounted on hi-temp insulation panel: six wires plus shield.

(d) The channels shall be numbered 1 through 14 and the terminals identified:



2) Termination box (at input area). The termination box shall contain the following:

(a)

Test Site	Channels
20-inch	6
21-inch	6
Set-up	0

(b) Pin connectors: six wires plus shield.

(c) The channels shall be numbered 15 through 20 and the pins identified with the same coding used for the strain-gage terminals.

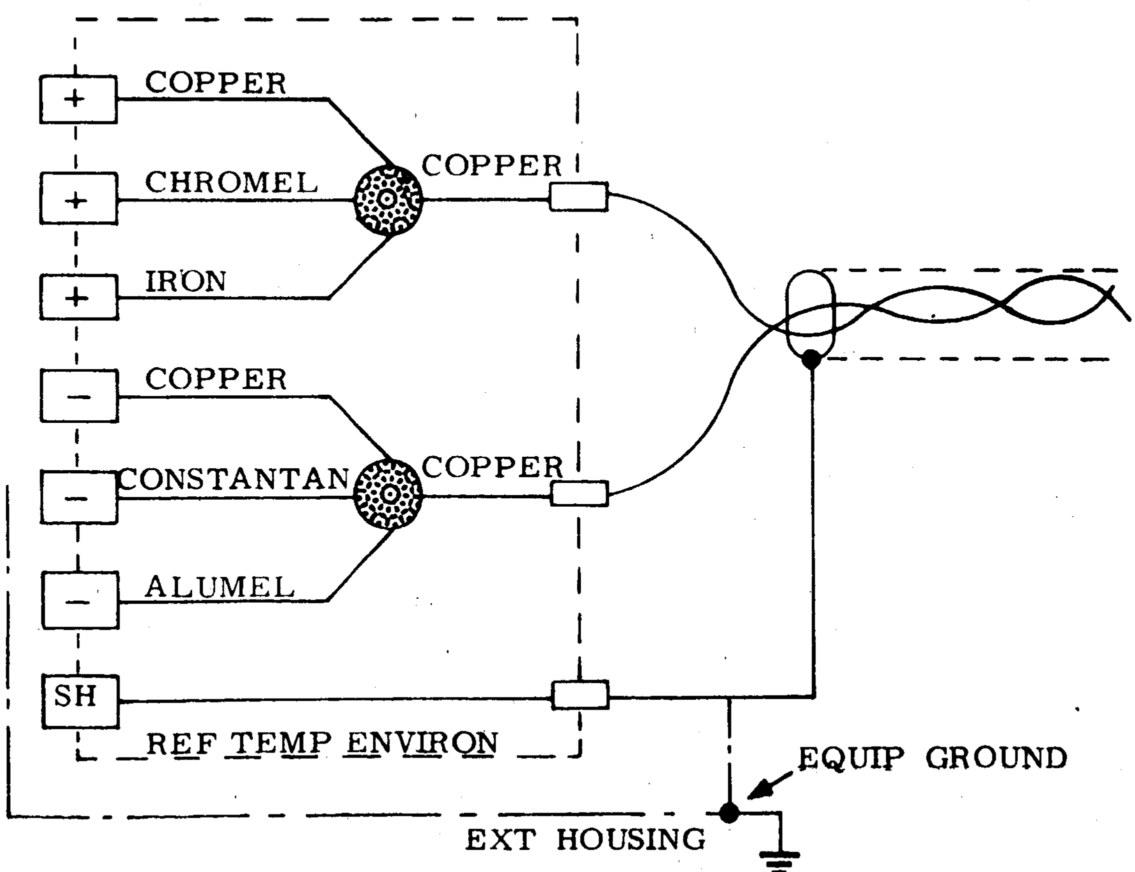
(d) The box shall be of a type similar to the Hoffman oil tight push button enclosures 12 PBX (6 spares).

3) Thermocouple channels.

(a) Thermocouple reference junctions shall be located in input area.

(b) Approved quick connect terminals shall be provided.

(c) Junction wiring:



(d) Blocks of 50 channels required. These units shall be portable from site to site.

(e) Twisted, individually shielded and jacketed thermocouple wire will be used by JPL.

(f) A method of patching from the reference junction output to the strain-gage channel input is required.

4) Digital registers. A convenient means of patching signals into the digital registers at the test input area is required.

5) Monitoring. A convenient means of patching into the system, monitoring the signal output, and making operational adjustments of bridge balance and excitation voltage is required. A convenient means of selecting any channel for display, in digital form is required in the test control area. The analog channel patch panel in the common area shall have sufficient spares for future wiring in of 54 additional input channels and the wiring in a 54-pair cable from the JPL Central Recording Station. (The CRS cable will be used to transmit high frequency analog signals to CRS for recording).

3.7 Construction and physical requirements.

3.7.1 General.

a. Service-proven components, subsystems and methods shall be used throughout the entire system whenever possible.

b. Modular plug-in, solid state circuits shall be used throughout the entire system whenever possible, and shall adhere to JPL Specification 20061 where applicable.

c. All equipment shall be constructed and mounted to permit accessibility to any and all component parts for ease of maintenance and replacement.

d. All construction and fabrication shall be of the highest quality according to electronic industry standards.

e. All terminals, plugs, and circuit wiring shall be numbered or identified in some unique manner, both on the equipment and on the drawings, for ease of identification and location.

f. All units of the system shall fit through a standard size door, 3 feet by 6 feet 8 inches.

3.7.2 Operating environment. Room ambient temperature will be from 65 to 90°F; humidity shall be 10 to 90 percent. No special cooling equipment will be provided by JPL.

3.7.3 Power source. Both 115 volt and 230, 60 cycle ac power lines shall be available. The voltage tolerance is 115 ±10 volts and 230 ±20 volts for a frequency tolerance of 60 ±3 cycles per second. Power failures shall cause the system to fail safely, i.e., power surges caused by loss of or restoration of power, either deliberate or uncontrolled, shall not cause any abnormal operation or overloading. The contractor shall state the amount of ac power required, and circuit breaker equipment required.

3.7.4 Space allocation. The space allocation shall be:

Area	Equivalent floor area
Test Input	5' x 10'
Test Control	3' x 5' (table top mounted desired)
Test Output	10' x 10'
Computer Common Equipment	17'6" x 16'7" and 17'6" x 12'7"

3.7.5 Cable runs. Lengths indicated on JPL Drawing 6-9133 188.

3.8 Self test. The system shall include a performance analyzer. The performance analyzer shall operate independently of the computer. The self test shall consist of the introduction of known voltages, the digitized output compared to limits set up on a tolerance switch, and when the tolerance is exceeded the system stops on that channel. A jack shall be available for an external (JPL-supplied) counter to count the number of errors. Manual patching of voltages is satisfactory for the strain gage channels.

3.9 Documentation. The following documentation, in reproducible form, shall be furnished with the Data System:

One complete set of schematics covering all equipment furnished.

One complete set of wiring diagrams, layouts, and sketches of all terminal equipment patch panels with corresponding color codes and designations used.

One complete set of interface drawings showing terminations and routes taken, showing approximate lengths of runs, etc.

One set of operational procedures.

One set of control panel layouts.

3.10 Workmanship. The Data System shall reflect in an industrial sense the highest quality craftsmanship, and where applicable, shall adhere to JPL Specifications 20014 and 20016.

4. QUALITY ASSURANCE PROVISIONS

4.1 Contractor inspection. The contractor shall be responsible for performing all necessary quality control inspections to ensure compliance with all the product and material requirements specified herein.

4.1.1 Visual inspection. A visual inspection shall be performed on 100 percent of production of all materials, components, hardware, assemblies, etc., prior to, during, and after fabrication, for each item produced. A mutually agreed upon method of inspection marking shall be used, if applicable.

4.1.2 Electrical inspection. Electrical inspection shall be 100 percent of production, prior to, during, and after fabrication.

4.2 Performance testing. The contractor shall provide JPL with sufficient signed and dated documentation (test data and reports) to verify that the completed equipment meets all of the performance requirements of this specification under the environmental conditions specified, prior to and upon delivery.

a. The contractor shall conduct a system demonstration test at his facility in accordance with written procedures approved in advance by JPL personnel. These tests shall demonstrate the performance of the system in all of its operating modes.

b. The contractor shall conduct an over-all system checkout and demonstration test upon completion of the installation of the system at JPL. These tests shall show full compliance with this specification.

4.3 Quality control. The contractor shall ensure to the satisfaction of JPL that he has available, and utilizes correctly, gauging, measuring and test equipment of the required accuracy and calibration, and that the instruments are of the proper type and range to make measurements of the required accuracy. The contractor shall have available a set of master gauges, standards, and appropriate instruments to conduct regularly scheduled calibrations of his inspection and test equipment. Records of such calibrations shall be maintained, dated and signed by the contractor and made available for JPL review and inspection.

4.4 Rejection and resubmittal. Delivered equipment that fails to meet all the requirements of this specification shall be rejected and returned to the contractor. Prior to resubmittal, the contractor shall furnish the JPL procurement division and the JPL cognizant engineer full particulars, in writing, regarding the cause, and action taken to correct the defects.

5. PREPARATION FOR DELIVERY

Not applicable.

6. ENGINEERING NOTES

1) Teletype punches BRPE-110 are to be used for the test output area punches.
2) The system shall be scaled so that ±4000 is full scale.